

International journal
for science, technics and
innovations for the industry



MACHINES
TECHNOLOGIES
MATERIALS

YEAR XI **Issue 1 / 2017** **ISSN PRINT 1313-0226**
ISSN WEB 1314-507X



Published by
Scientific technical
Union of Mechanical Engineering "INDUSTRY 4.0"



MACHINES. TECHNOLOGIES. MATERIALS

INTERNATIONAL SCIENTIFIC JOURNAL

PUBLISHER

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING “INDUSTRY 4.0”

108, Rakovski Str., 1000 Sofia, Bulgaria

tel. (+359 2) 987 72 90,

tel./fax (+359 2) 986 22 40,

office@stumejournals.com

www.stumejournals.com

ISSN PRINT 1313-0226, ISSN WEB 1314-507X, YEAR XI, ISSUE 1 / 2017

EDITOR-IN-CHIEF

Prof. D.Sc. DHC Georgi Popov,

President of Bulgarian Scientific and Technical Union of Mechanical Engineering

EDITORIAL BOARD

MEMBERS

SCIENTIFIC COMPETENCE

Prof. Dimitar Damyanov	Automatisation of production
Prof. Dimitar Karaivanov	Mechanics of machines
Prof. Dimitar Stavrev	Technologies and materials
Prof. Dimitar Yonchev	National and industrial security
Prof. Galina Nikolcheva	Machines tools and technologies
Prof. Hristo Shehtov	Automatisation of production
Prof. Idilija Bachkova	Automatisation of production
Prof. Ivan Kralov	Mechanics of machines
Prof. Ivan Parshorov	Technologies and materials
Prof. Ivan Yanchev	Machines and technologies
Prof. Ivo Malakov	Automatisation of production
Prof. Kiril Angelov	Industrial Management
Prof. Lilo Kunchev	Transport Equipment and Technology
Prof. Lubomir Dimitrov	Machines and technologies
Prof. Miho Mihov	Agricultural machinery
Prof. Miroslav Denchev	Ergonomics and design
Prof. Mladen Velez	Economics and Marketing
Prof. Nikolay Diulgerov	Technologies and materials
Prof. Ognyan Andreev	Production management
Prof. Petar Kolev	Transport Equipment and Technology
Prof. Roman Zahariev	Robotics
Prof. Sasho Guergov	Robotic systems and technology
Prof. Tsanka Dikova	Technologies and materials
Prof. Vitan Galabov	Mechanics of machines



MACHINES. TECHNOLOGIES. MATERIALS

INTERNATIONAL SCIENTIFIC JOURNAL

ISSN PRINT 1313-0226, ISSN WEB 1314-507X, YEAR XI, ISSUE 1 / 2017

EDITORIAL BOARD FOREIGN MEMBERS

Prof. Adel Mahmoud	IQ	Prof. Marian Tolnay	SK
Prof. Ahmet Ertas	TR	Prof. Mark Easton	AU
Prof. Andonaq Londo	AL	Prof. Mart Tamre	EE
Prof. Andrei Firsov	RU	Prof. Maryam Ehteshamzade	IR
Prof. Andrzej Golabczak	PL	Prof. Michael Evan Goodsite	DK
Prof. Anita Jansone	LV	Prof. Movlazade Vagif Zahid	AZ
Prof. Aude Billard	CH	Prof. Natasa Naprstkova	CZ
Prof. Bojan Dolšak	SI	Prof. Oana Dodun	RO
Prof. Christian Marx	LI	Prof. Oleg Sharkov	RU
Prof. Dale Carnegie	NZ	Prof. Páll Jensson	IS
Prof. Ernest Nazarian	AM	Prof. Patrick Anderson	NL
Prof. Esam Husein	KW	Prof. Paul Heuschling	LU
Prof. Ewa Gunnarsson	SW	Prof. Pavel Kovac	RS
Prof. Filipe Samuel Silva	PT	Prof. Per Skjerpe	NO
Prof. Francisco Martinez Perez	CU	Prof. Péter Korondi	HU
Prof. Franz Haas	AT	Prof. Peter Kostal	SK
Prof. Genadii Bagliuk	UA	Prof. Juan Alberto Montano	MX
Prof. Georg Frey	DE	Prof. Raul Turmanidze	GE
Prof. Gregory Gurevich	IL	Prof. Renato Goulart	BR
Prof. Haydar Odinaev	TJ	Prof. Roumen Petrov	BE
Prof. Hiroyuki Moriyama	JP	Prof. Rubén Darío Vásquez Salazar	CO
Prof. Iryna Charniak	BY	Prof. Safet Isić	BA
Prof. Ivan Svarc	CZ	Prof. Sean Leen	IE
Prof. Ivica Veza	HR	Prof. Shi Xiaowei	CN
Prof. Jae-Young Kim	KR	Prof. Shoirdzan Karimov	UZ
Prof. Jerzy Jedzejewski	PL	Prof. Sreten Savićević	ME
Prof. Jean-Emmanuel Broquin	FR	Prof. Stefan Dimov	UK
Prof. Jordi Romeu Garbi	ES	Prof. Svetlana Gubenko	UA
Prof. Jukka Tuhkuri	FI	Prof. Sveto Cvetkovski	MK
Prof. Kazimieras Juzėnas	LT	Prof. Tamaz Megrelidze	GE
Prof. Krasimir Marchev	USA	Prof. Tashtanbay Sartov	KG
Prof. Krzysztof Rokosz	PL	Prof. Teimuraz Kochadze	GE
Prof. Leon Kukielka	PL	Prof. Thorsten Schmidt	DE
Prof. Mahmoud El Gammal	EG	Prof. Tonci Mikac	HR
Prof. Manolakos Dimitrios	GR	Prof. Vasile Cartofeanu	MD
Prof. Marat Ibatov	KZ	Prof. Yasar Pancar	TR
Prof. Marco Bocciolone	IT	Prof. Yuriy Kuznetsov	UA
		Prof. Wei Hua Ho	ZA

CONTENTS

MACHINES

COMPARATIVE RESEARCH ON THE QUALITY OF AUTOMOTIVE STATORS CONDUCTORS WELDING OBTAINED THROUGH BRAZING AND TIG WELDING METHODS PhD, P. Eng. Pushev G., Chief Assistant Velev S., Prof. Dulgerov N.	3
STUDY OF RESISTING MOMENT INFLUENCE ON OPERATION OF HIGH-VOLTAGE INDUCTION MOTOR PUMP ELECTRIC DRIVE Assoc. Prof. Rachev S. PhD., Lyubomir Dimitrov, Ivaylo Dimitrov	7
ABOUT COMPUTER DESIGN OF MACHINE AND EQUIPMENT THE GENERAL MACHINE BUILDING Dinev G. PhD., Iliev Zh. PhD.	11

TECHNOLOGIES

APPLICATION OF LOW-FREQUENCY VIBRATION PROCESSING AT A PERFORMANCE RESTORATION OF STEAM TURBINE BLADES Candidate of Technical Sciences, associate professor Savinkin V., Director of Remplazma LLP Kiselyov L., master, research associate Kolisnichenko S., Junior researcher mitry Koptyaev D., Master, research associate Derman A.	15
EXPERIMENTAL RESEARCH AND MODELING OF THE IMPACT OF PLASTIC DEFORMATION ON DIFFERENT MATERIAL CHARACTERISTICS Leo Gusel	17
IMPROVING THE RELIABILITY OF INSTRUMENTS FOR MEASURING AND THERMAL CONTROL OF OBJECTS OF DIFFERENT PHYSICAL NATURE BY THE FINISH ELECTRON-BEAM PROCESSING SURFACES OF OPTICAL ELEMENTS Associate Professor Ph.D. Yatsenko I., Professor dr. eng. Antonyuk V., senior researcher dr. eng. Kyrychenko O., Professor dr. eng. Vashchenko V.	20
STUDY OF EFFECT OF INITIAL AND SUBSEQUENT HEAT TREATMENT OF CON-STRUCTIONAL STEELS ON PROPERTIES OF JOINT WELDS PRODUCED BY ELECTRON BEAM WELDING Engineer Izyumov Artem A., Engineer Artem Gubko D.	24
A REVIEW OF RESIDUAL STRESS MEASUREMENTS BY HDM AND OPTICAL TECHNIQUES M.Sc. Barile C. PhD, Prof. Casavola C. PhD, M.Sc. Pappaletta G. PhD, Prof. Pappalettere C.	27
THE POSSIBILITY OF USING WASTE MOLD SAND FOR ADSORPTION OF ACETIC ACID Assoc. Prof. Štrkalj A. PhD., Assoc. Prof. Glavaš Z. PhD., Prof. Hršak D. PhD.	30
CALCULATION ALGORITHM FOR CYCLE LENGTH OF SIGNALIZED INTERSECTION Assist. Prof. PhD Saliev D.	33

MATERIALS

ALUMINUM NANOSTRUCTURED COATINGS AS ALIGNMENT LAYERS FOR LIQUID CRYSTAL MIXTURES Prof. Dr. Alexander G. Smirnov, Dr. Andrey A. Stsiapanau, Prof. Dr. Victor V. Belyaev, Dr. Denis N. Chausov	35
--	----

COMPARATIVE RESEARCH ON THE QUALITY OF AUTOMOTIVE STATORS CONDUCTORS WELDING OBTAINED THROUGH BRAZING AND TIG WELDING METHODS

Сравнително изследване качеството на завареното съединение при електросъпротивително и
електродъгово заваряване на статорите на електрогенератори

PhD, P. Eng. Pushev G.¹, Chief Assistant Velev S.¹, Prof. Dulgerov N.²

M & T 2001 Limited¹, IMS-BAS²

tony_velev@abv.bg

Abstract: *The goal of the project is to compare the quality of automotive stators conductors welds produced by means of Brazing and TIG welding. As a result of the performed experiments and microstructural analysis of the welded joints, we have been able to prove the advantages of the brazing method over the TIG method.*

Keywords: CONDUCTORS, HYBRID STATORS, BASKET OF STATOR.

Introduction

It is well known that the quality of the welding process is of critical importance for the quality of the starters armatures and alternators stators. The goal of this research is to study the most popular welding methods applied in welding the stator conductors and the armature commutator.

The most popular welding methods applied for this purpose are the TIG and the brazing welding methods. The laser method has not been under consideration due to information from some users about serious doubt for danger to the operators' health. The TIG method is realised by using a very high temperature (the arc temperature reaches up to 10,000 °C) and an inert gas for protection, usually argon, needs to be used. The brazing method is realized by 720 °C and an additional material - a Sil-Fos band (85% Cu and 15% silver).

Experiments for conductors welding process

The goal of these experiments has been to study the welded joints of the conductors and to compare the resulting strength between the TIG method and the brazing method (copper-silver 15% band). The cooling during the brazing welding is carried out by water or by an air-powered "Vortex Tube cooler". The experiment was to study the strength of the welded seam by using destruction of the welded connection by a test machine. (See Fig.1-2)

- The tensile test results (table 1) have shown that the brazed joint is 30% stronger than the joint realized by TIG welding. The joint obtained by the brazing method is stronger than the base metal. This joint always tears away from the base metal directly to the welded joint. See Fig.3.

Reliability of the welded joint obtained by the brazing method

The metallographic analysis of the welded joint by employing brazing method has shown that it is solid and without pores or hot cracks. The welding layer is without cracks and inclusions. Please refer to Fig.4-5 for the metallographic photos.

Reliability of the welded joint obtained by the TIG method

For the analysis, the metallographic pictures of samples obtained by the TIG method have been studied under an electron microscope. (Fig.6-7). The metallographic analysis of the TIG welded joint has shown:

- coarse crystal structure in the welding zone (Fig.8)
- non-metallic inclusions (Fig.9)

- the welding zone is not solid and has big pores. Please refer to Fig.9-10 for the metallographic photos.

Furthermore, the analysis of the obtained results shows that the TIG welding has many disadvantages compared to the brazing method. The most important are:

- TIG welding method - The high welding temperature makes the copper very aggressive and helps for the formation of pores in the welding area; in brazing method the welding temperature is 720 °C and such pores have not been found. This result explains why the strength of the brazed joint is almost two times stronger compared to TIG.
- TIG welding method – can easily go out of control, while the brazing method can be controlled very precisely.
- TIG welding method - a very expensive method, compared to the brazing method!
- TIG welding method – lack of consistency of the welded joints.

- TIG welding method - very difficult to repair wrong welds compared to the brazing method.
- TIG welding method – there is a safety concern; the high temperatures cause unhealthy emissions, thus are posing higher health risks! Also, it is bad for the environment.

We have made a comparison in the electro resistance of the stator conductors ends welding. The comparison is between two of the most popular welding methods: brazing and TIG. Please see below in the table 2 obtained results. All measurements of the electrical resistance have been made by a precision ohmmeter. The results of the experiments unambiguously indicate that the brazing process has less electrical resistance, respectively less electric and thermal losses. These measurements have been performed at room temperature, but it is known that the losses will increase with increasing the ambient temperature.

The gathered results unambiguously show the advantages of the brazing method compared to the TIG method.



Fig.1 Destruction process of the samples on the test machine to determine the strength of the welded joint.



Fig.2 Recording the extension during the sample demolition for creating a stress-strain diagram.

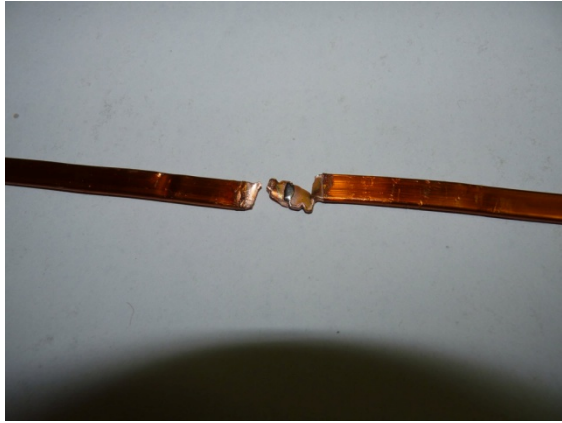


Fig.3 The sample after tearing.

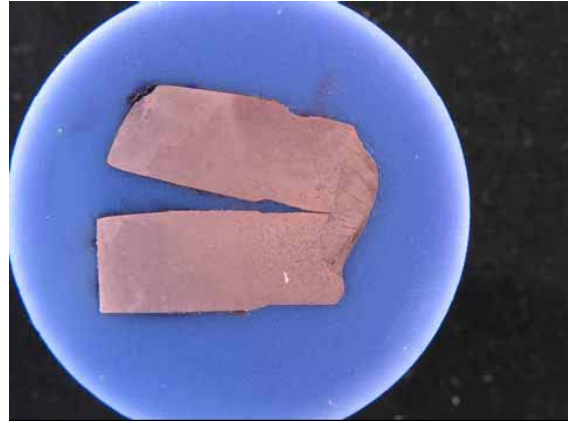


Fig.6 Metallographic sample of weld obtained by TIG welding

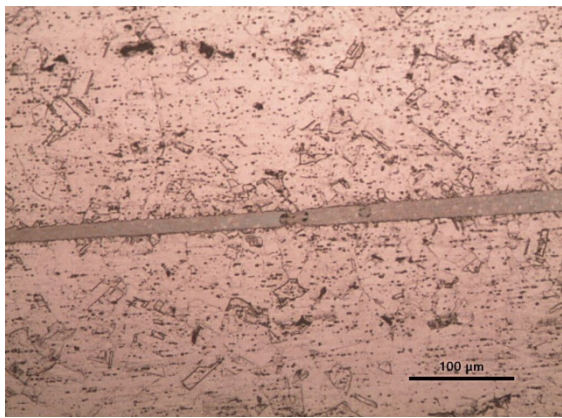


Fig.4 Metallographic structure of welded joint

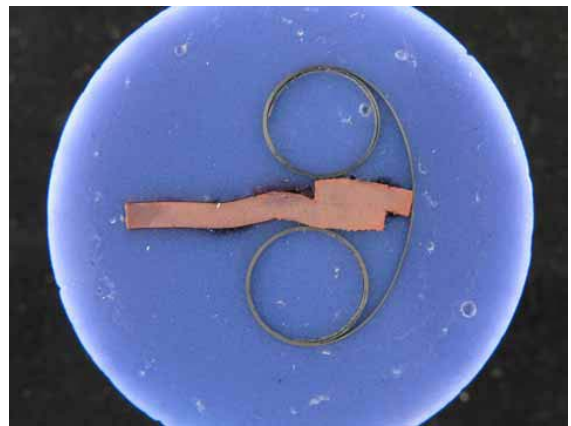


Fig.7 Metallographic sample of welded joint obtained by brazing method

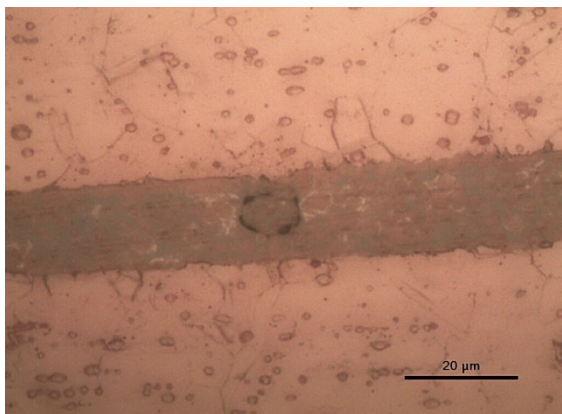


Fig.5 Metallographic structure of welded joint

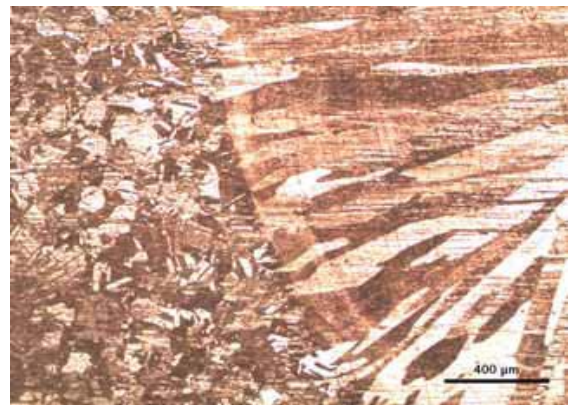


Fig.8 Crystal structure in the welding area

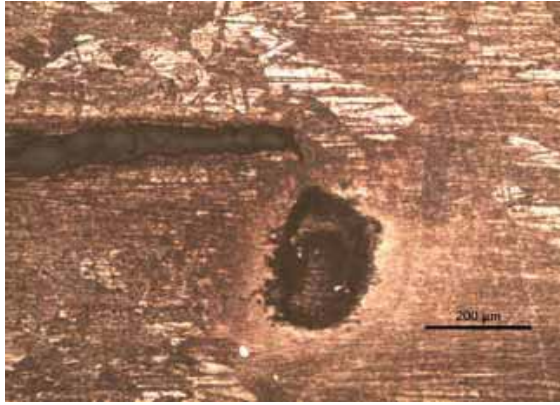


Fig.9 Cracks in the welding area

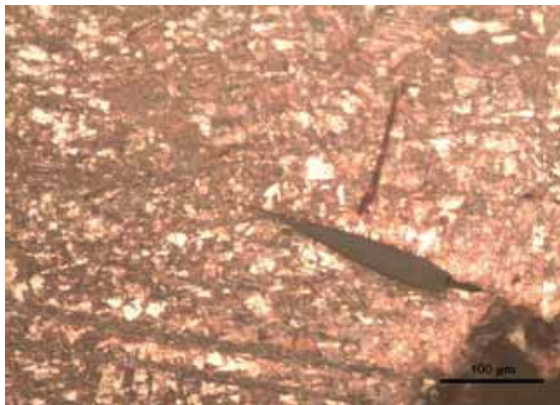


Fig.10 Non-metallic inclusion in the area of welding

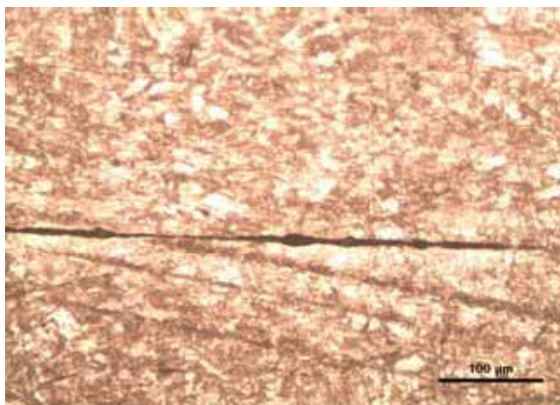


Fig.11 The microstructure of TIG welding layer

Table 1

TENSILE TEST OF WELDED JOINT	
BREAKING FORCE P _{max} (daN)	
TIG WELDING	BRAZING
60	103

Table 2

Sample #	Brazed $\mu\Omega$	TIG $\mu\Omega$
1	102	117
2	105	114
3	100	116
4	97	114
5	102	114
6	105	113
7	98	116
8	99	117
9	98	112
10	102	115
11	106	117
12	99	113
13	102	115
14	106	117
15	107	115
16	99	112
Average	101,6875	114,8125
Range	10	5

STUDY OF RESISTING MOMENT INFLUENCE ON OPERATION OF HIGH-VOLTAGE INDUCTION MOTOR PUMP ELECTRIC DRIVE

Assoc. Prof. Rachev S. PhD. ¹, Lyubomir Dimitrov ¹, Ivaylo Dimitrov ¹,
Technical University of Gabrovo ¹, Republic of Bulgaria

sratchev@mail.com

Abstract: Paper deals with dynamic behavior of powerful electric drive for pump unit. The practical application of these electric drives is diverse. In industry they drive a wide range of mechanisms connected to them. Some of them are pumps with varying degrees of security for thermal or nuclear power plants. The nature of the flow of transient processes in the electrical machine often determines the behavior of the entire system, an element of which is the machine. As a result the values of the energy losses components in the induction motor have been obtained according to different values of initial resisting moment. Some of the study results have been presented graphically. An analysis has been made and conclusions from the results obtained have been done.

Keywords: HIGH-VOLTAGE TECHNIQUES, INDUCTION MOTOR DRIVES, ELECTRIC MACHINES, MODELING, ENERGY CONVERSION

1. Introduction

Electricity represents one-third of all energy consumed around the world. Growing energy prices are causing the industry and consumers to rethink things. Therefore the future belongs to solutions for low energy consumption in the sector of industrial plant. So the challenge is to develop a wide spectrum of energy-efficient solutions [1].

Induction motors with squirrel-cage rotor are the most common type motors. They are cheap, with the most simple and reliable construction and easy maintenance. The absence of collectors and brushes eliminates largely the conditions of arcing and makes them suitable also for fire and explosive environments.

The shape of the torque-speed characteristics makes induction motors with squirrel-cage rotor particularly suitable for drive centrifugal pumps with a quadratic dependence of resisting torque versus angular speed align naturally with the mechanical characteristics of the electric motors. The shape of mechanical characteristic varies depending on the structure of the rotor. Double-cage motors have a higher starting torque, which makes them more suitable for loads with a relatively large initial resisting torque and a relatively larger mass.

If the initial resisting torque of the load is significant, or that its mass is so large that time for acceleration is unacceptably high, the outcome is either to use a more powerful motor with cage rotor, which is oversizing, or use another type of motor.

In assessing the economy of an electric drive in the first place should take into account the loss of power and energy that occur when operating the mechanism driven.

2. Features of medium voltage electric drives for pump units

Broadly speaking, the drive of medium voltage (MV) is used in high power driven load. For units with high power has a margin of capacity in the range 500-10000 kW and more.

Currently it is well known widespread shift towards more efficient technical solutions for reducing consumption of energy and the losses during operation.

Subject of research is calculating the parameters of movement and dynamic loads of widespread mechanism - a centrifugal pump.

There are several hundred identifiable types of pump design tailored for varying volume throughputs and delivery heads, and including many specialized designs for specific fluid applications. The most common type, accounting for perhaps 80 per cent of fluid transfer applications, is the broad 'centrifugal pump' category [2].

Hydraulic machines as appearing pumps have been significant development and application in all areas of life. Working hydraulic machines convert mechanical energy into potential and kinetic energy of certain quantities of a fluid. Most often they are powered by electric motors.

Usually this type of electric motors are running under constant load indefinitely, reaching a thermal steady-state condition, i.e. continuous duty S1 [3].

Resisting torque of each turbo-mechanism is derived from the aerodynamic (or hydraulic) torque and resistance torque determined by mechanical resistance (friction in the bearings, gears and in others.).

With some approximation it can be considered that between the shaft torque and the rotational speed of centrifugal pumps a correlation exists $T \sim \omega^2$. Practically speed exponent varies between 2-6 for different structures and working conditions that need to be considered when selecting electric drive. Specified limits are determined at the pumps by the presence of static head. In general, the mechanical characteristic feature is the significant reduction in resisting torque in reducing angular speed. It should be borne in mind and even landed turbo mechanism has a significant aerodynamic drag and consequently the shaft torque constitutes at a rated speed of about 40% of the nominal. When calculating the starting characteristics of such electric drives is not recommended initial resisting torque be taken for less than 25% nominal static resisting torque of turbo mechanism. For most pumps the power, and hence the starting torque is less than 50% of the nominal value.

The pumps usually are started at closed throttle valve in the pressure line, i.e. while placing flow is 0. This method of starting in most cases is to eliminate bumps and pressure pulsations in the hydraulic system. Starting at closed throttle valve in the pressure pipe as a rule eases and conditions of employment of the drive motor.

Once the pump is put into operation, it should not work in a closed valve more than one to a few minutes, because liquid is heated, and the individual parts, thereby reducing clearances and risk of seizure arise. There is also the danger of damage to the shaft seal.

The correct clearances and fits are a basic but important part of a pump's fitness for purpose. The importance of obtaining the accurate dimensions, particularly on bore diameters, increases with pump size [2].

In the cases of non-compliance for placing pumps in operation, receiving an overload of electrical motors, which drive them, and very often they are burned.

The power of the motor which drives the pump is usually chosen slightly larger (by 10-20%) of the power to drive the turbo

machine at its nominal operation. The need for such stockpiling having the kind of characteristic of her that turbo machines are often used for work in modes other than the nominal.

Losses in turbo machines are three types: hydraulic, volumetric and mechanical. The hydraulic losses are obtained by fluid flow through the machine. Volume losses represent the amount of any omission of flow from the machine outside and flow that returns from the pressure to the suction side of the machine. The mechanical losses are the result of mechanical friction between stationary and rotating parts of the machine, such as friction bearings and sealing box. All these losses have an impact on the pumps efficiency.

It's necessary coordination of the operating point of the motor for normal operation of electric drives. It consists in that the operating point of the motor, i.e., the intersection of the characteristics of the torque of the motor and load to be located near or slightly below the point with coordinates 'rated torque - rated speed'. In this way it is ensured motor cooling - on the one hand, the losses emitted in the form of heat are within the design, on the other - the speed of rotation of the cooling impeller mounted on the shaft of each standard induction motor, it is sufficient to provide design flow of air.

Important is the motor type - with induction motors with squirrel-cage rotor heat is released completely in the machine itself.

It is also taking into account mechanical shocks during start and ripple of the load. Any abrupt change in torque, either from the motor or from the side of the load, leading to mechanical stresses and fatigue in the shafts. Also, for pumps abrupt changes in torque can lead to hydraulic shocks in the system. This is one of the factors, along with thermal overload and increased energy losses in frequent releases to prefer methods with soft start, such as placing a soft starter or frequency converter. The last one provides an additional advantage - it can cover changed in resistive load during operation and also allows quick passage through any resonant frequencies at start and avoid work at these frequencies.

By the way in industry 80% of operated machines have no requirements for maintaining accurate torque and speed, but only a fraction of the drives require work at very low speeds or high performance regulation.

The need for speed control is evident when itself technological process requires it. But there are other cases where such adjustment is appropriate. For example in circulating centrifugal pumps in systems with small static head, reducing the speed, respectively, flow rate by 20% results in a reduction of power consumption by up to 50%.

The greater is the static head in the system, the smaller the economy, but still have it. Therefore, where the technological process enables a reduction in productivity using frequency regulation can be implemented very large energy savings. Additional savings, including by increasing the lifetime of the equipment come from a change in the cycle of work – less frequent starts and stops at a lower flow rate.

Methods for starting and control the rotational frequency [4]

Direct starting is undoubtedly the simplest and cheapest method, as long as the power system and the characteristic of the load to allow it.

In the starting methods using start with reduced voltage is achieved reducing starting current, but also an even greater reduction in starting torque. Thus these methods are applicable to loads with low initial resisting torque.

Applicable are also and non-electrical means for regulation of the resisting torque of the load. One possibility is the starting of centrifugal pumps with closed pressure pipe-line and gradually opening after acceleration the motor. The method is applicable to both synchronous and induction motors, provided that the

technological process allows it. It must be selected suitable plumbing fittings or used pumps with controllable steering system, which is appropriate only for large capacities. Regulation of the pumps performance in a continuous duty in this way is inadvisable because it is accompanied by losses and wear of the hydraulic equipment.

Another possibility is to use a hydraulic clutch. It allows to modify the speed of the mechanism driven, not amended the rotational speed of the motor. When it is typical that in the initial moment of acceleration motor is loaded only with internal resistance of the clutch. With the rise in motor speed increases the amount of hydraulic fluid pumped to the clutch impeller and thereby increasing motor torque applied to the load. The selection of characteristics of the hydraulic clutch so as to fit the mechanical characteristics of the load is a complex engineering task. In operating mode after accelerating the motor to the rated speed, clutch remaining work, as has its own slip, causing heat in it and respectively – energy losses. The hydraulic clutch is capricious device that requires maintenance. All these shortcomings make its use more rarely.

Frequency converter control still remains relatively expensive method for induction motors with squirrel-cage rotor MV, but with significant advantages over other methods of starting and especially to regulate the speed in operation:

- Frequency converters provide start, stop and speed control ranging from 0 to over-synchronous speed; occupy relatively little space and have small losses.
- Hold most flexible starting characteristics suitable for all loads.
- Completely missing abrupt changes of current and torque typical for moments of switching to other starting methods.
- Even with drives where technology does not require a speed change during operation in some cases frequency converters can implement substantial energy savings by reducing operating speed.
- They are not sensitive to the parameters of the scheme as other starting devices, so that the selection of apparatus is not so complicated task and tolerate future changes in the pattern, including the replacement of the motor.

A specific problem of frequency drives are high-voltage peaks fed to the motor. These peaks arise from the trapezoidal shape of the output voltage pulses of inverters with PWM, which have very steep front (high dv/dt).

High frequency surges increase the risk of disruptive voltages and vagabond currents in the shaft and breakthroughs in motor bearings. These phenomena lead to overheating and arcing occurs and an electric arc, disrupting the bearings.

3. Mathematical model

Transient processes when starting a powerful electric drive of pump unit are considered. Speed variations depends on the total torque of inertia of the rotating masses [5].

In studies we use the parameters of the T-shaped equivalent circuit of the motor which are determined by calculation methodology of the manufacturing company to slip $s = 1$.

The electric motor, the object of development, is induction motor with double-cage rotor, produced by IHB Electric JSC, Bulgaria. whose technical data and parameters at slip $s = 1$ are given in the Appendix.

We transform the three-phase system into a two-coordinate system. The equations for the voltages of the windings of the induction machine are represented in a coordinate system rotating at the synchronous rotational speed. Using this coordinate system provides the convenience that the system of differential equations attend important parameter of the induction machine slip s .

The complete system of differential equations representing mathematical model of electromechanical system of electric drive for pump unit consists of five equations. After converting equations for voltages of windings and presenting expressions received in the

form of *Cauchy*, for ease of solving them, we get four equations to model stator currents. Fifth equation is fundamental relationship between torques, so called equation of motion [6]. It includes torque developed by the electric motor and resisting torque of the pump unit. Engineering accuracy requirements in studying the dynamics of the pump unit driven by induction motor, fully able to meet with using one-mass dynamic model. The torque-speed characteristics of pumps are often approximately represented by assuming that the torque required is proportional to the square of the speed, giving rise to the terms 'square-law' load [7].

The total moment of inertia of the electric drive I_{TOT} is set by means of factor of inertia FI as

$$I_{TOT} = FI \times I_r \quad (1)$$

where

I_r – rotor moment of inertia.

We use system relative units participating in the equations values. In this system voltages, currents, power and parameters are expressed in parts of the underlying values of those variables. As basic values are nominal values of current, voltage, power, torque, speed, resistances. Amending the scale of time using relatively time $\tau = \omega_b t$ – e.g. time in relative units.

Below are outlined the various components of energy and energy losses during starting and steady-state regime of the induction motor.

Adopted energy from the grid in starting mode is:

$$W_{ST} = \sum_{k=0}^{a_{n-1}} [(P_{a_k}) \tau_n] + \sum_{k=0}^{a_{n-1}} [(P_{b_k}) \tau_n] + \sum_{k=0}^{a_{n-1}} [(P_{c_k}) \tau_n] \quad (2)$$

a_{n-1} – number of point of the time axis, which lasts until the transient process.

P_{a_k} , P_{b_k} , P_{c_k} – power consumed respectively by phase A, phase B and phase C.

Adopted energy from the grid at steady state mode is:

$$W_{SS} = \sum_{k=a_{n-1}}^{n-1} [(P_{a_k} + P_{b_k} + P_{c_k})] (n-1) \delta t - t_n \quad (3)$$

δt – a discrete of time axis in seconds;

t_n – duration of the transient process in seconds.

The energy losses in butts (frontal connections) in starting mode are:

$$W_{1ST} = 0.5 r_1 \sum_{k=0}^{a_{n-1}} [(I_{a_k})^2 + (I_{b_k})^2 + (I_{c_k})^2] \delta t \quad (4)$$

r_1 – resistance of one phase of the stator winding;

I_a , I_b , I_c – phase stator currents.

The energy losses in butts (frontal connections) in steady state mode are:

$$W_{1SS} = 0.5 r_1 \sum_{k=a_{n-1}}^{n-1} [(I_{a_k})^2 + (I_{b_k})^2 + (I_{c_k})^2] \delta t \quad (5)$$

The energy of moving parts and effective work in starting mode is:

$$W_{MMST} = 0.5 J \omega_b^2 + T_L \omega_b t_{a_{n-1}} \quad (6)$$

J – total inertia moment of the electric drive;

ω_b – rated circular frequency; T_L – resisting torque, Nm

The energy of moving parts and effective work in steady state mode is:

$$W_{MMSS} = \sum_{k=a_{n-1}}^{n-1} [T_k \omega_k \delta t] \quad (7)$$

Heat released in motor in starting mode:

$$W_{HST} = W_{ST} - W_{MMST} \quad (8)$$

Heat released in motor in steady state mode:

$$W_{HSS} = W_{SS} - W_{MMSS} \quad (9)$$

4. Results obtained

Solving of differential equations system which describes the dynamic behavior of pump electric drives is a complicated task. Because of this reason there is a need of applying of numerical methods for integrating in combination with micro-processor devices.

To solve the differential equations system the software MathCad® of Parametric Technology Corporation (PTC®) has been used and specifically laid down therein functional method "Rkadapt" - method for solving differential equations with adaptive size of approximating step.

The format of the function in method mentioned is:

Rkadapt(y, x₁, x₂, npoints, D)

y - vector of initial conditions;

x₁, x₂ - points defining the boundaries of the range, which will seek a solution of differential equations. The initial conditions set out in y concern at point x₁;

npoints - number of points in the given interval, which will be carried approximation;

D - vector of the right side of the system differential equations containing the first derivatives of the unknown variables /functions/.

Using the proposed mathematical model, the components of energy losses have been calculated in case of different values of initial resisting torque and factor of inertia. Some of the results obtained are presented in the paper – Table 1, Figure 1 and Figure 2.

Table 1: Influence of initial torque and factor of inertia FI

T_{INIT}^*	FI	t_{ST} , s	W_{ST} , $\times 10^{11}$ Joule	W_{SS} , $\times 10^{11}$ Joule	W_{1ST} , $\times 10^6$ Joule	W_{1SS} , $\times 10^5$ Joule	W_{MMST} , $\times 10^7$ Joule	W_{MMSS} , $\times 10^{11}$ Joule	W_{HST} , $\times 10^{11}$ Joule	W_{HSS} , $\times 10^{11}$ Joule
0.2	2.0	4.755	3.401	4.017	2.275	0.903	6.811	8.820	3.400	4.016
	2.5	3.693	2.825	4.893	2.632	0.997	6.575	9.735	2.825	4.892
	3.5	3.376	3.008	5.171	3.188	1.025	7.659	10.010	3.007	5.170
	4.5	3.341	3.351	5.202	3.647	1.028	8.985	10.040	3.350	5.201
	5.5	3.424	3.788	5.129	4.053	1.021	10.410	9.968	3.786	5.128
0.25	2.0	4.850	3.509	3.942	2.294	0.895	6.894	8.739	3.508	3.941
	2.5	3.702	2.851	4.885	2.650	0.996	6.583	9.727	2.850	4.884
	3.5	3.385	3.037	5.162	3.210	1.024	7.667	10.000	3.036	5.161
	4.5	3.350	3.383	5.194	3.672	1.027	8.994	10.030	3.382	5.193
	5.5	3.435	3.826	5.119	4.082	1.020	10.420	9.959	3.825	5.118
0.3	2.0	4.943	3.614	3.871	2.312	0.887	6.973	8.660	3.613	3.870
	2.5	3.710	2.875	4.878	2.668	0.996	6.590	9.721	2.874	4.877
	3.5	3.396	3.067	5.153	3.233	1.023	7.676	9.991	3.066	5.152
	4.5	3.361	3.417	5.184	3.698	1.026	9.003	10.020	3.416	5.183
	5.5	3.447	3.867	5.107	4.112	1.019	10.430	9.948	3.866	5.106
0.4	2.0	4.954	3.664	3.862	2.344	0.886	6.983	8.651	3.663	3.861
	2.5	3.726	2.924	4.864	2.706	0.994	6.603	9.708	2.923	4.863
	3.5	3.419	3.128	5.133	3.278	1.021	7.696	9.973	3.127	5.132
	4.5	3.384	3.487	5.164	3.752	1.024	9.023	10.000	3.486	5.163
	5.5	3.473	3.950	5.085	4.172	1.016	10.460	9.928	3.949	5.084
0.5	2.0	4.887	3.644	3.914	2.378	0.892	6.925	8.710	3.643	3.913
	2.5	3.839	3.065	4.767	2.744	0.984	6.701	9.612	3.064	4.766
	3.5	3.438	3.187	5.116	3.325	1.020	7.712	9.958	3.187	5.115
	4.5	3.525	3.700	5.039	3.808	1.012	9.145	9.883	3.699	5.038
	5.5	3.498	4.035	5.062	4.233	1.014	10.480	9.907	4.034	5.061

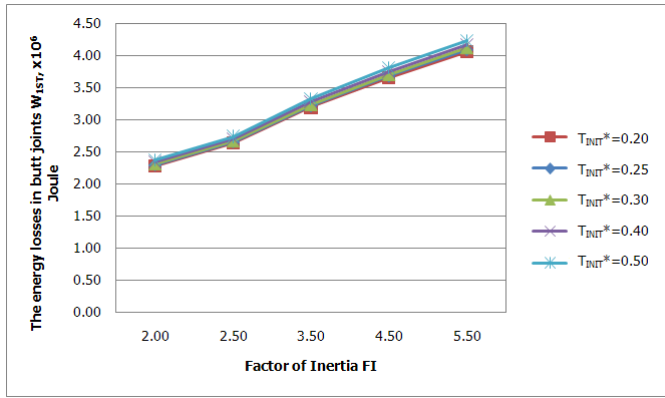


Fig. 1 Heat released in motor W_{IST} in starting mode versus factor of inertia FI .

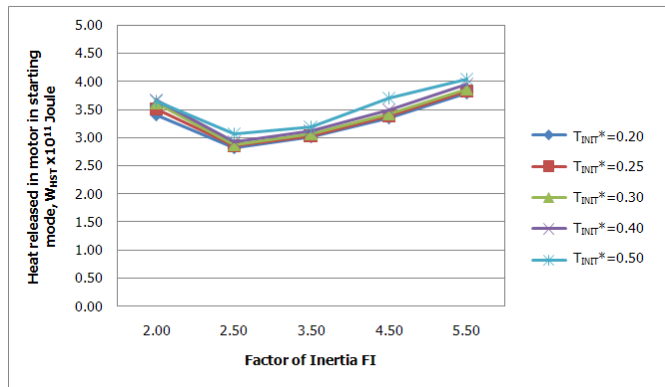


Fig. 2 The energy losses in butt joints W_{HST} in starting mode versus factor of inertia FI .

5. Conclusions

The operation of the complex system of production unit – motor has been studied. Following work on the model of the mechanical system - pump in coordination with the rated mechanical characteristic of induction motor is obtained function $\omega=f(t)$, it appears slip of an induction motor $s=f(t)$, which determines the nature of its dynamic load. All values are presented in the time domain.

Dynamic changes are determined by the balance of torques, i.e. when the load increases on the motor shaft slip increases, which decreases the reduced active rotor resistance, which increases the current in the rotor, and hence the torque of the shaft, i.e. all variables related to the features of an induction motor follow the dynamic changes of slip.

Confirmed the assertion that the selection and sizing of the drive system is influenced by the range of variation of static torque, which is the ratio of static torques at minimum and maximum loading of mechanism (usually calculated at nominal speed).

The mathematical model developed in the paper helps to examine the transient processes when starting a powerful electric drive for pump unit. The mathematical model developed makes it possible to determine the proper design and selection of mechanical parameters in order to achieve customized requirements.

The energy losses in butt joints in starting mode нарастват с нарастването на Factor of Inertia FI .

The heat released in motor during starting е най-малка при Factor of Inertia $FI=2.5$, което се явява оптимален вариант.

Acceleration time depends to a greater extent from the value of the inertia moment of the electric drive as a whole and, to a lesser

extent by the value of the initial resisting torque of the pump unit driven.

The acceleration time is directly proportional to the load inertia moment, including the rotor of the motor and the inversely proportional to motor torque. If the motor can not provide a big enough motor torque and acceleration time becomes too large, it can lead to motor overheating due to overcurrent.

The detailed study of electromagnetic and electromechanical transient processes makes possible the most rational design of induction electric drives.

Appendix

INDUCTION MOTOR DATA AND ELECTRIC EQUIVALENT CIRCUIT PARAMETERS

Description	Data
Rated power (P_{rated})	2850 kW
Rated stator voltage (V_{rated})	6000 V
Operating frequency (f)	50 Hz
Line stator current (I_l)	335.841 A
Rated torque (T_{rated})	27442 Nm
Pole pair number	3
Rotor speed (N_r)	992.263 rpm
Power factor	0.845
Rotor torque of inertia (I_r)	275 kgm ²
Stator resistance r_1	0.05 Ω
Rotor resistance r_2'	0.062 Ω
Stator leakage reactance x_1	0.957 Ω
Rotor leakage reactance x_2'	2.237 Ω
Magnetizing reactance x_m	34.826 Ω

References

- 1 www.bodospower.com
- 2 Clifford Matthews, *Engineers' Guide to Rotating Equipment. The Pocket Reference*. London and Bury St Edmunds, UK, Professional Engineering Publishing Limited, 2002, pp. 153, 176.
- 3 Rotating electrical machines - Part 1: Rating and performance, EN 60034-1, 2010.
- 4 <http://www.engineering-review.bg/>
- 5 H. Merz, *Electrical Machines and Drives*. Berlin, Germany: VDE VERLAG GMBH, 2002, pp. 348-355.
- 6 R. Crowder, *Electric Drives and Electromechanical Systems*. Oxford, U.K.: Elsevier, 2006, pp. 35-42.
- 7 A. Hughes, *Electric Motors and Drives*. Oxford, U.K.: Elsevier, 2006, pp. 369-375.

ABOUT COMPUTER DESIGN OF MACHINE AND EQUIPMENT THE GENERAL MACHINE BUILDING

Dinev G. PhD.¹, Iliev Zh. PhD.²,
Technical University, Bulgaria ¹
University of Mining and Geology "St. Ivan Rilski", Bulgaria ²

halkopirit@mail.bg

Abstract: We grounded the motivation of students to develop and use catalogue in their work. Examples with family planetary reducers are given and the construction of safety over flow valve is discussed as well as its rotor eccentric crusher in mine industry. A 3D model of rotor crusher is presented with the catalogues numbers of crushing and flywheel head. We made computer investigation of repercussion plates of crusher and their static movement. The results are analysed and recommendation are made about improvement of construction. A conclusion about relationship between competitive power of products and quality of training in higher technical education was made.

Keywords: COMPUTER DESIGN, CATALOGUE MATERIALS, FINITE ELEMENT METHOD, ECCENTRIC CRUSHER TYPE,

1. Introduction

The continuous improvement of produced product quality and their competitive power is one of the important criteria for formulation and realization of firm strategy. For this purpose of control of quality find greater application during the last years of our country. This is based on the concept for evaluation of conformity with European market, because the introduction of a system for control of quality guarantees products conformity. On the other side the product proposed to the market must satisfied the needs of consumers to have competitive power. This is based mainly on the continuous development of consumers needs because of which the product quality is a developing category. Therefore are given product remains with high quality until an analogous products satisfying completely elements needs appear in the market [12, 15].

If is assumed that the consumer has sufficiently good choice them his evaluation for the quality is reliable. But the purchasing power is determined not only by quality but also from the price, which determines its competitive power. For this reason the use various firms strategies is recommended. On the base of strategy developed by Reichwald and Piller for open innovations, individualization and new forms of division of labor might be generated chain of arguments [15]. According the authors [2] these arguments may lead to concrete proposals for better technical decisions and markets parameters of the product.

Regarding the design production and marketing of created product the technology Product Life Management (PLM) must be needs it allows improvement of quality, reduces the price and them until the product let out to market [16].

This requires qualified technical and non-technical specialists for time work which must be ensured by our universities. They must developed their qualification on the principle "Learning a live time" in order to be able to work on suitable positions in modern productions [8, 14].

In the present work we treated on problems for motivation and training students in professional qualification on machine and general engineering for computer design of mechanical products.

The main problems are:

- Analysis of computer design of mechanical drives and equipment in mining industry;
- Searching of variants for suitable constructive decisions;
- Development of 3D geometrical models of technical products and simulation analysis;

2. Consideration the student motivation to develop and use catalog materials.

The aim of tis investigation was to give reasons to students to gain experience for development and use of catalogues during their training in design, production and exploitation of products.

This must begins with fundamental objects of study ensuring the necessary knowledge and experience in computer design of mechanical products [3] using suitable and tested decisions for laboratory work [1, 4]. Later with optional subjects related to simulation analysis of product [6, 7].

For satisfying the need of consumers with a wide the of products is necessary to use possibilities of typing and unification in the process of design. This can be illustrated by working out of mechanical operation through a family of gear transmissions.

2.1. Optimal design of gear transmission.

In developing the concept for the design of a gear transmission with cylindrical gears is determined its functional structure and appropriate solution. For the purpose the already developed method according grounded criteria can be used and to make technical estimation for taking decision [5].

In the case are considered three variants of toothed gearings: planetary gear, Worm gear and cylindrical multi-stage gear which evaluated by experts according the following criteria:

- High velocity ratio;
- Simple construction;
- Self-locking;
- Low noise level;
- Coefficient of efficiency;
- Compactness of construction;
- Low expenses;
- Manufacturability.

The obtained and the possible number of points are calculated and compared according VDI-225 normal and the given methodology [5]. The result from the made test shows that the most suitable variant according the possible points number is the choice of planetary reducers. On Fig.1 are presented 3D geometrical models of family planetary reducers.

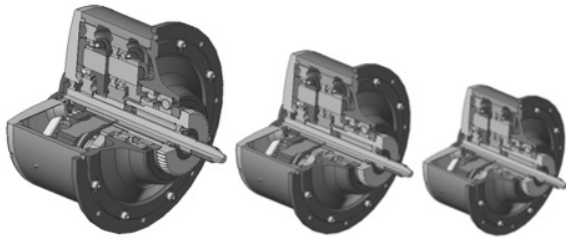


Fig. 1 3D geometrical models of family planetary reducers.

For grounding the kinematic scheme of the chosen variant of gears is approach for generation of multi-stage gears. It is based on synthesis and analysis of loading of gears, coefficient of efficiency etc. after a number of variants is reached, but not all of them have practical sense in concrete case [5].

One of important work of constructor in the process led of product design is to create simulation model and to study its conduction as assembled unit.

For the purpose during training of students from professional qualification "General Engineering" is developed and tested a 3D geometrical model of safety overflow valve (Fig.2). The worked out method for laboratory work in Solid Works is used. It is also looking for collisions in assembling, simulation of the reciprocating movement at various regimes as well as simulation fluid analysis [9]. The high speed distribution of fluid in valves chamber at opening during operation in production conditions is given on Fig.3.

During operation and repair of the product the specialist must be able to create and make explosive design and to choose elements from catalogue spares. The 3D model (Fig.4) is of rotor crusher of eccentric type used in mining industry [10, 11]. It will be one example for making out, exploded models with detail parts. On Fig.5 is shown the crushing parts [11, 18] with catalogue numbers of corresponding assembled units 6000 for crash care their numbers cylinder with eccentric haft, 6100 for belt head- stock and 6200 for flywheel head - stock. Catalogues numbers (Fig.6) for individual details flywheel head - stock in their numbers are 6201-6209.

The possibilities of expert systems for investigation of geometrical concentrators of tension, monitoring and diagnosis of bearings and gear reducers by operation and other mechanical products must be learn by further specialists [4]. Such a task for investigation of tensions maybe done for different elements of concentrators on a given equipment. We shall study the repercussion plate of crusher and analysis its deformational and pre-stressed connection during operation. The limit conditions applied to the plate with working force of crushing (Fig.7).

Fig.8 shows that maximal tensions according von Misses in plate are $129\,349\,296\text{ Nm}^2$ or $129,349\text{ MPa}$, which gives coefficient of safety $FOS=4,8$ (Fig.9). The existing concentrators of tensions are in the bolt junctions (where the plate are assembled) and in site of repercussion plate hang up. These results are normal and expected.



Fig. 2 Safety – overflow valve

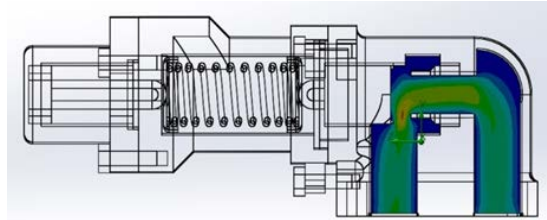


Fig. 3 Field of velocity of valve

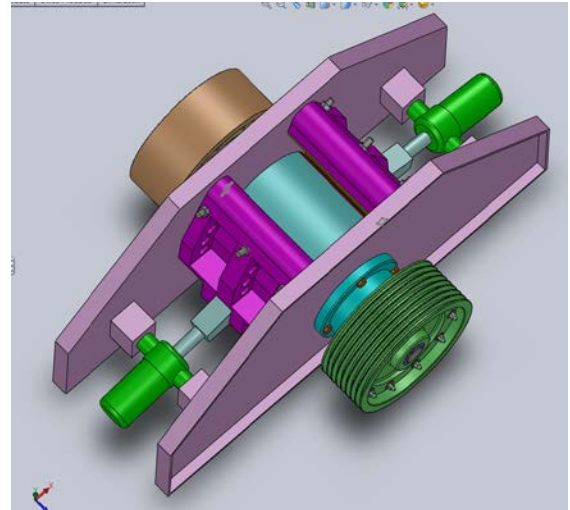


Fig. 4 3D – model of rotor eccentric crusher

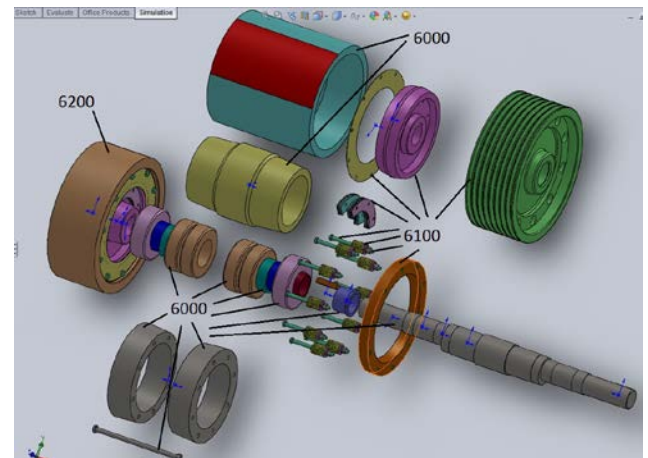


Fig. 5 Catalogue numbers of the crushing head of the crusher

The picture of deformational shifting (Fig.10) shows that is maximal value is along the central part of plate, where the force of crash is applied and is $0,031\text{ mm}$, these values are in tolerance limits.

The following documents to guarantee products with required quality and to be put on the market are required:

- Test procedure of the product;
- Service manual and conservation;
- Guarantee card and service;
- Packing of the products;

In the process of construction may be for some details expected constructive elements for lifting, moving, for example reducers or protection of journal on important shaft during the transport. For better market parameters of the product advisable to use automatized assembling of units through possibilities of mechatronic systems [13, 14].

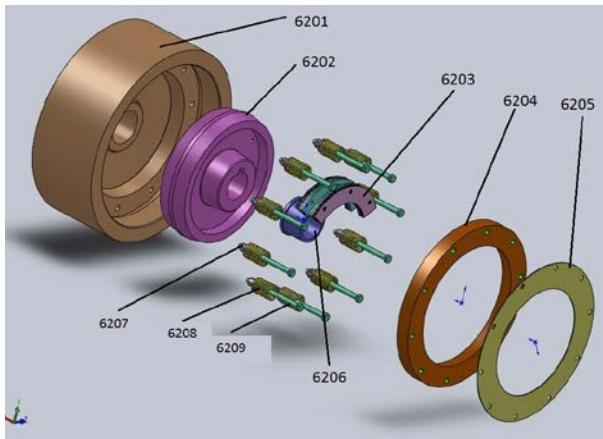


Fig. 6 Catalogue numbers of the of flywheel head of the crusher

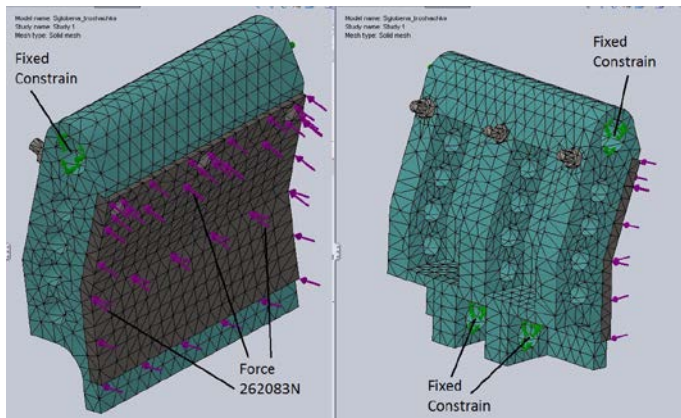


Fig. 7 Boundary conditions imposed on the reflecting plate and its sampling

3. Activities of students in Joint Programme

In training students as future engineers must be considered the education quality in college and to continue with succession of chosen specialty in the university.

The question for quality and competitive power of products is related to education quality in higher engineer specialists..

The main prerequisites for hard work in labs according European Credit System (ECTS) are in innovation systematic work during the year, computer knowledge and practice. This might be done with better contacts with students and formation of main body of excellent students which provoke increased interest in the others. As a result the activity of students and PhD students for mobility to universities abroad from joint Program will increase. This collaboration is also useful for universities presented in accepting country.

4. Conclusions

On approach for motivation of students for work with catalogues at design, manufacturing and operation of products with high quality and competitive power using informational systems war developed.

A method for choice of optimal variant of constructive decision of mechanical transmissions –reducers and rotor crusher of eccentric type was worked out.

Exploded drawings together with catalogue numbers of component assembled units and details, which may be used at preparation of catalogues for spares were made.

3D model of rotor crusher of eccentric type, which may be investigated for dynamic and static analysis by the Finite Element Method (FEM) was developed. Result for tension state safety factor and static shift of repercussion plates were received.

The results are useful in increasing interests of students and PhD students during their training, exchange for learning and investigation work according joint programs in universities abroad as getting in to work in high-technology industries.

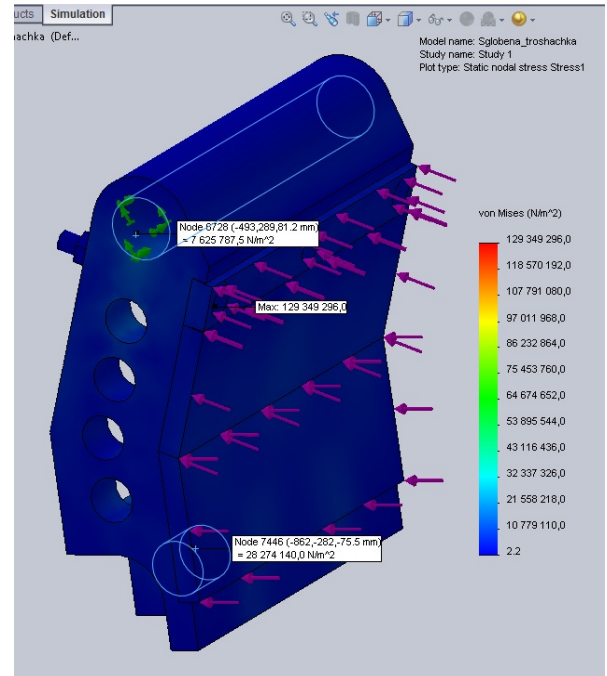


Fig. 8 Distribution of equivalent stress on CAD-CAE model of the reflective plate

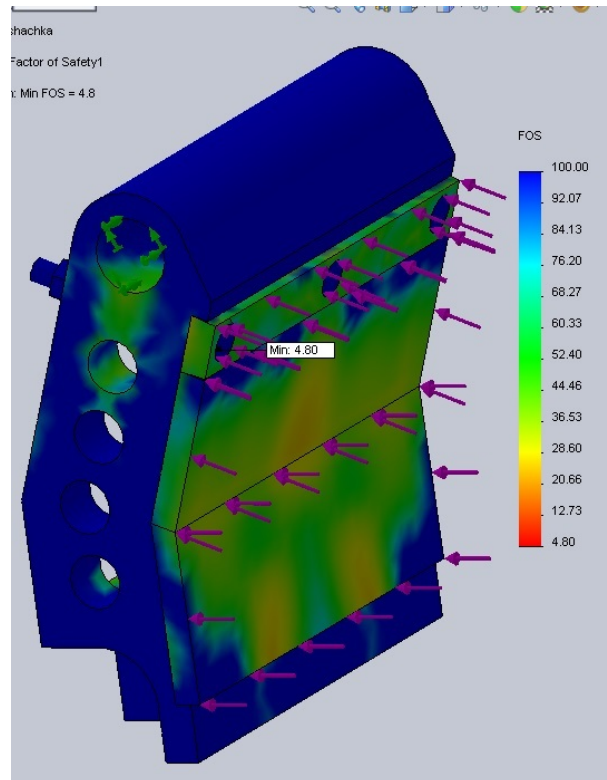


Fig. 9 Distribution of the factors of safety (FOS) on the reflecting plate

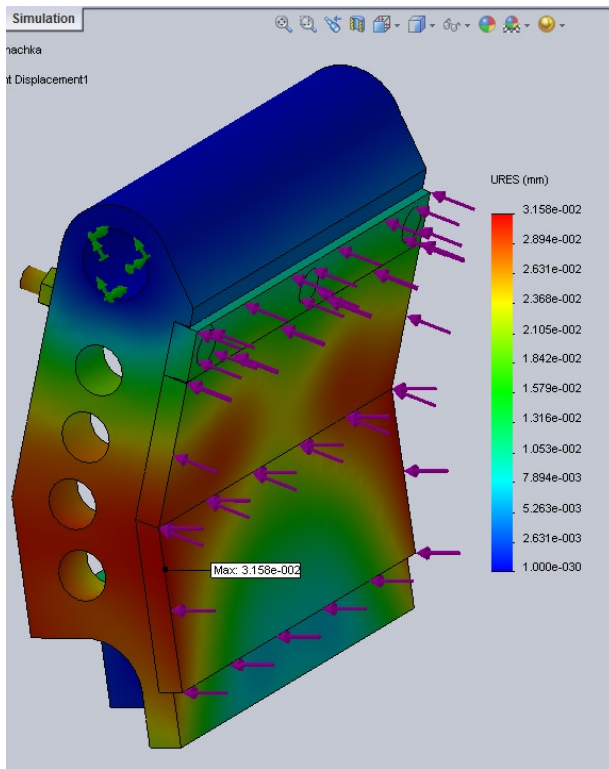


Fig. 10 Distribution of static displacement on the reflecting plate

ACKNOWLEDGEMENTS

This investigation is related to realization of activities according educational cooperation network CIII-BG-0722-05-1617 of Central European Education Program System.

References:

1. Angelov P.: Computer Aided Design, In: Publishing House RU "Angel Kanchev", Rousse, 2011 (In Bulgarian).
2. Debro A., P. Blazek, M. Kolb Value-based selling with the support of configurators. Proc. of 7th International Conference on Mass Customization and Personalization in Central Europe, September Novi Sad, 2016, 58-62.
3. Dinev G. Course on principles of mechanical design. In: AVANGARD PRIMA, 2011.
4. Dinev G., Z. Vitlarov Handbook for laboratory exercises on principles of design. In: AVANGARD PRIMA, 2011.
5. Dinev G. Fundamentals of design documentation of gear transmissions with cylindrical gears, SOFTTREID, 2004 (In Bulgarian).
6. Dinev G. An approach for simulation design of mechanical assembled unit. In: Journal Advanced Material Research, Vol. 463-464, Trans Tech Publication, Switzerland, 2012, p.1085-1088.
7. Dinev G.: Expert systems used throughout the training of master engineering in the field of industrial engineering. In: I international virtual journal for science, technics and innovations for the industry, MTM, Year IX Issue 1/2015, ISSN 1313-0226, p. 25-28.
8. Dinev G. Fundamental training in computer aided design for professional qualification within the field of general engineering. In: International virtual journal for science, technics and innovations for the industry, MTM, Year X Issue 1/2016, ISSN 1313-0226, p. 25-28.

9. Dinev G., K. Tujarov Simulation flow analysis of safety overflow valve. Transilvanja University of Brasov, Bioatlas 2016, Journal of Eco Agri Tourism, Vol.2, 2016.
10. Iliev Zh., N. Perenovski. Opportunities for using the finite element method by computer research on a rotary crusher of the eccentric type 800dx75, International multidisciplinary scientific symposium "Universitaria Simpro" (Petrosani, Romania), 2014, p. 516-521.
11. Iliev Zh., N. Perenovski., „Using finite element method by design of impact crusher for average crushing“, Academic Journal of "Mechanics, Transport, Communications", 2014, p. VII-21-VII-28. (In Bulgarian).
12. Kuzmanovic S. Idustrijski Dizajn, Publishing House in University of Novi Sad, Faculty of Technical Science, 2012.
13. Malakov, I. Optimization of size ranges of technical products. In: General automation of the discrete production, ISBN 978-619-167-153-3, TU-Sofia, Sofia, 2015, pp. 25-48.
14. Malakov, I., Tz. Georgiev, V. Zaharinov, A. Tzokev, V. Tzenov. Demand modeling for the optimization of size ranges. Proceedings of the 26th DAAAM International Symposium, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-07-5, ISSN 1726-9679, Vienna, Austria, 2016, pp. 0435 □0444.
15. Reichwald R., F. Piller Interactive Wertschöpfung. Open Innovation. Individualisierung und neue Formen der Arbeitsteilung. Wiesbaden, Germany: Gabler Verlag / GWV Fachverlage GmbH, 2009.
16. Zafirov D. Voice of European Industry (What kind of technical specialists and documentation it needs), Bulgarian Journal for Engineering design, Vol.2, march, 2009, pp.10-13.
17. <http://www.solidworks.com/>
18. <https://bg.wikipedia.org/wiki/SolidWorks>

APPLICATION OF LOW-FREQUENCY VIBRATION PROCESSING AT A PERFORMANCE RESTORATION OF STEAM TURBINE BLADES

ПРИМЕНЕНИЕ НИЗКОЧАСТОТНОЙ ВИБРАЦИОННОЙ ОБРАБОТКИ ПРИ ВОССТАНОВЛЕНИИ РАБОТОСПОСОБНОСТИ ЛОПАТОК ПАРОВЫХ ТУРБИН

Candidate of Technical Sciences, associate professor Savinkin V.¹. Director of Remplazma LLP Kiselyov L.² master, research associate Kolisnichenko S.¹. Junior researcher mitry Koptyaev D.¹. Master, research associate Derman A.¹ "NKSU named after M. Kozybayev" RSE on REU (Republican State Enterprise on the Right of Economic Use)¹, NKR Remplazma LLP¹, Petropavlovsk, Kazakhstan
E-mail: cavinkin7@mail.ru, remplazma@mail.ru, serega5@mail.ru, derman68@mail.ru, koptyaev29@mail.ru

Abstract: the present article examines the technical and economic advantages of vibratory stress relief from the restored steam turbine blades. It is presented the background technology of the offered vibration method of the structure stabilization of weld metal that improves the operational reliability of turbine blades.

KEYWORDS: VIBRATION PROCESSING, WELD FACING, LOW-TEMPERATURE CRACKS, RESIDUAL STRESSES, TURBINE BLADE, METAL STRUCTURE

1. Introduction

The highly effective energy saving technological processes finds an extensive application in industry. In particular a low-frequency vibration processing belongs to such processes. More often application it finds for the decreasing of residual stresses at welding structure production [1,2]. Vibration processing in comparison with heat treatment allows considerably improving the organization of production.

2. Method relevance

The economic effect of the vibratory stress relief in comparison with the heat treatment is expressed in the following: the compact equipment can be installed in any point of the production shop; low operational costs; power consumption is much lower; the sizes and weight of the details are not almost limited; details surfaces aren't oxidized.

It is found that the significant effect on the low-temperature cracking in welding structures from middle and high-alloyed steel is rendered by residual stresses. Especially it concerns the products subjected to cyclic loadings. The first effort of the research in this direction showed that the critical stress of the low-temperature cracking as a result of a heat treatment and vibration approximately identical and makes 20-25%. On the other hand a vibration processing is almost not effective for cold-drawn materials since at the same time there is a distortion of a crystal latitude. Considering that at the production of a welding structure it is often used the cold-rolled metals, and after welding the seams and in particular a zone of a thermal influence is exposed to pro-forging, it is appropriate to make the vibratory stress relief in a complex with heat treatment. It is connected with the fact that a vibration processing doesn't change metallurgical structure of a metal. At the same time vibration processing needs to be carried out before heat treatment.

3. Main part

Recently, the method of restoration of working blade tips of the steam turbines with the use of a deposit welding is widespread in the world practice. Despite the recommendations of the certain authors about the need when welding to apply the materials of an austenitic class as additive materials, the problem of vibratory stress relief remains urgent. Undoubtedly, the use of the specified additive materials in the course of welding at a strict observance of a task requirements, the value of running energy and the sequence of welding don't allow to stabilize the structure of weld metal enough. In this regard the values of a residual stress need to be reduced

unambiguously. Especially it touches the steam turbines blades manufactured from the high-chromium steel of martensitic -ferritic class. PT-13/90 and K-300-240 turbine blades of the last stage were restored. The restoration of the working tips was carried out with a multiple-bead deposit. After a multiple-bead deposit and HEZ (heat effective zone) pro-forging, the blades were subjected to low-frequency vibration tests at the stand presented on (the figure 1 – Vibration stand for tests of the turbines blades).

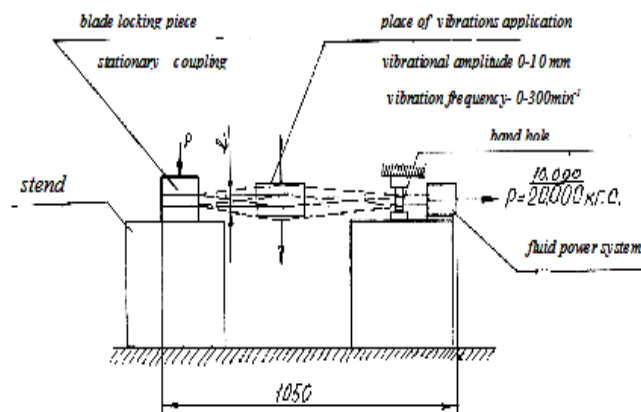


Fig. 1 Vibration stand for tests of turbines blades

Vibration processing was carried out on the following modes: frequency - from 0 to 200 Hertz; acceleration – to 10g; detail weight – 14 kg; the size in the plan – 1200 x 1200 mm; drive power – 10 kw; processing duration – 20-30 min.

After the vibration processing the working tips were subjected to face-hardening by a spraying method with a follow-up thermal reflowing of the stellite powder on the proven technology and carried out the machining with a profile finishing of a working blade in the drawing sizes.

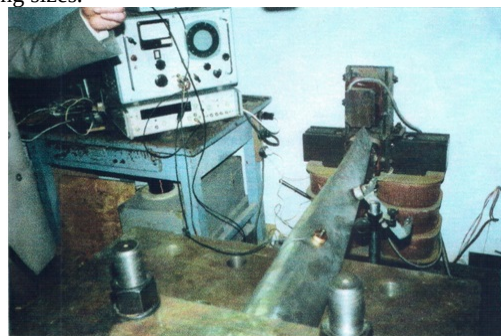


Fig. 2 Vibration tests of blades at the stand in the conditions of "Remplazma" LLP Petropavlovsk

At a compliance of a blades profile to the technical requirements the residual stresses were fixed with the IKN-1M-4 device, the functional principle of which is based on a magnetic memory of metal, the developer is "EnergoDagnostika" LLC. Here the use of the phenomenon of the units and parts magnetization while in operation for the identification of stresses concentration zones. This method was timely applied to the turbine blades definition which has the stresses concentration zones at a predestruction stage. An additional point is that the offered way of diagnostics allowed to define the vibration tone, i.e. to estimate its vibration reliability according to the characteristics of a field distribution of residual magnetization along a blades tip surface.

By researches it is established that the application of the hard-facing processes considerably reduces the fatigue durability of the restored details [3]. For turbine blades, working in the conditions of sign-variable cyclic loadings and restored by plasma spraying, fatigue durability was estimated by the following parameters: in coefficient of stresses concentration ($\alpha_\sigma = \sigma_{\max}/\sigma_H$), where $\sigma_{\max}$ – the maximum stresses are in the area of coverage of stresses concentration, MH/MM²; σ_H – rated voltage in the same section, MH/MM² and a large-scale factor of distribution ($\varepsilon_\sigma = \sigma_{-1d}/\sigma_{-1}$), where σ_{-1d} – the limit of a sample endurance of any diameter, MH/MM²; σ_{-1} – a limit of samples endurance with a diameter of 7,5 mm, MH/MM².

On the tests results it is established that an origin and development defect zone coincides with the plane of the design section. At the same time the concentration of the internal stresses increases in a point of the critical section. At the subsequent blade loading, the concentration of internal stresses increases in metal that is followed by the change of a structural component. Concentration of the internal stresses at the bending moment was fixed by the IKN-1M device, and results are presented in the form of the schedule (figure 3).

The test was carried out on the length of a blade working tip, in the places of the most subjected mechanical and erosive dynamic wear. Scanning by the sensor of the IKN-1M device was carried out from the radical section of a blade to peripheral or on the contrary.

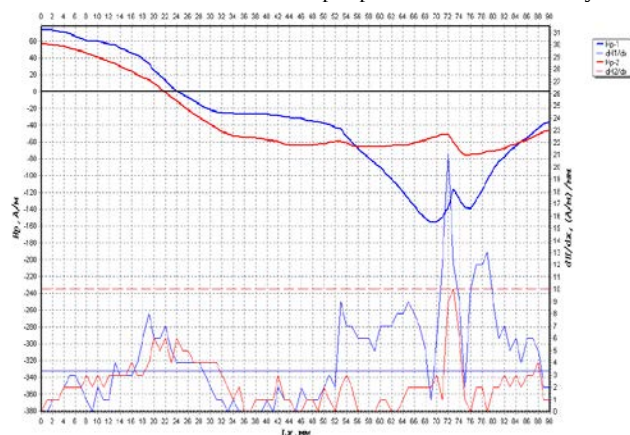


Fig. 3 Schedule of stresses concentration zones in a hydraulic cylinder rod

According to the characteristic of a field distribution of residual magnetization (H_p) along the blade surface, the tone of vibration was defined at the same time, i.e. the blade vibration reliability was estimated, based on the known effect of energy absorption of mechanical oscillations (damping of fluctuations), causes the corresponding growth of blade residual magnetization. The continuous red line on graphics (figure 3) shows the change of a magnetic field on a meter of a sample length (A/m) on which the accurate splashes aren't visible. The red dashed line shows the stresses admissible value for this type of a product. The blue continuous line of the schedule (gradient) shows the places of splash in KN on each mm of a sample (A/mm). The change of a sign shows about the direction of curvature.

On the control results the blade places working in the most intense conditions are defined. Such places are those ones which lines of stresses concentration and deformation (line H_p) are located cross and having the maximum coefficient of stresses intensity.

Values of this coefficient are defined automatically and displayed on the screen on the operator's call.

The stresses concentration zone is located in the places of defects appearance of a sample on 65-80 mm on the test length and on 6-8 mm from a critical point, (figure 3). If in a critical section at the chosen scheme of jamming, the bending moment and the operating stresses have the greatest value, then at a bend of other types these sizes are about 20-25% less.

The values of the residual stresses in a zone of restoration didn't exceed the threshold values. The metalstructure of a metal represented the sorbite focused on martensite. The hardness was HB 260-280.

Blades passed tests in compliance to the standards. The following results of the tests are received: amplitude – 0-20 mm; frequency – 50 min⁻¹; number of symmetric cycles $3,1 \times 10^{-6}$ before cracks emergence; number of symmetric cycles before cracks emergence for the blades which undergone a complex processing $5,2 \times 10^{-6}$.

After working off of the processing methods and modes on the prototypes according to this scheme it was carried out the works on the restoration of full-scale blades on two turbines, the blades served not less than on 10 000 m/hour.

4. Conclusion

Consequently, for the early recognition of stresses concentration zones it's shown the applicability of the "passive" methods of diagnostics using the energy of structure radiation: the method of acoustic emission and the method of a metal magnetic memory.

Tests results by these methods showed that the fatigue durability of TPP-2 turbine blades restored by a plasma spraying on "REMPLAZMA" NKSU-TOO technology is 16,3% more than the blades fatigue durability restored on the state standard specification 21448-75 technology.

This test method of the details on fatigue durability allows predicting the approach of possible defect on the stresses concentration zones on a detail, without removing it from the unit.

On the basis of the carried-out works it is established that the complex blades processing after their restoration by a weld facing increases the resistance to low-temperature cracks more than by 1,5 times. At the same time the structural disfunction of a metal basis wasn't observed.

6. List of references

1. Dudarov N. S., Janus Yu. R. – "Application of low-frequency vibration processing for the improvement of properties of welded connections and increase in geometrical stability of products" the State-of-the-art review for 1970-1985, No. 4108, Moscow 1986.
2. Stratfull R.F. Corrosion Testing of Bridge Decks/R. F. Stratfull, W. J. Joukovich, D. L. Spellman//Transportation Research Record No. 539. Transportation Research Board. 1975. - P. 50-59.
3. Savinkin V. V., Tomashets A. K., Kiselyov L.A. Justification of the chosen covering material at a plasma dusting of a basis material . Bolashak KARGU. Urgent problems of the present International scientific magazine No. 4(17). Karaganda Bolashak-Baspa 2008.

EXPERIMENTAL RESEARCH AND MODELING OF THE IMPACT OF PLASTIC DEFORMATION ON DIFFERENT MATERIAL CHARACTERISTICS

Leo Gusel
University of Maribor, Faculty of Mechanical Engineering
Maribor, Slovenia

leog@uni-mb.si

Abstract. Cold forming process in the plastic domain of deformation causes strain hardening in the formed material. Strain hardening can be used for practically all metals and alloys to increase most of mechanical characteristics, however ductility and some others are reduced. In the paper experimental researches of the influence of effective strain on change of main mechanical characteristics such as tensile strength, yield strength, impact toughness, and some other characteristics of cold formed material were carried out and analyzed.

The results of the experiments are presented in the form of graphs. Special mathematical models for determination of different properties were obtained. These models are especially helpful for prediction of mechanical and other properties of a cold formed material. Knowing the material properties and their changes during the cold forming processes is very important for quality of the product and for planning the right technology of the forming processes.

Keywords: STRAIN HARDENING, MECHANICAL PROPERTIES, METAL FORMING, COPPER ALLOY, ELECTRICAL CONDUCTIVITY, REGRESSION ANALYSIS,

1. Introduction

There is always an interest in development of copper alloys with a high electrical and thermal conductivity, good mechanical properties and microstructure stability up to high temperatures. A possible way to obtain this interesting combination of properties is to use a precipitation hardening system.

Detailed investigations of system Cu-Cr have shown that small additions of other alloying elements such as Zr, refine the microstructure and enhance the age hardenability of the binary alloy.

In the usual production process the mechanical properties of these ternary alloys are dependent mainly on the chemical composition and the thermo-mechanical treatment. But by cold forming the mechanical properties of alloy are changing because of strain hardening.

It is well known that any cold forming process in the plastic domain of deformation introduces strain hardening characteristics in mechanical response of the material treated [1-7]. Strain hardening can be used for practically all metals and alloys to increase hardness and tensile strength, however ductility is reduced [8, 9, 10, 11].

Knowing the mechanical properties of alloys and their changes during the cold forming is very important for economically production [12].

2. Experimental Work

The influence of cold forming on changing of tensile strength, yield strength, flow stress, electrical conductivity and impact toughness was examined in the experimental work.

For the testing material special copper alloy CuCrZr with 0, 71% Cr and 0, 05% Zr in copper matrix was used. This is a copper – chrome – zirconium alloy with high electrical and thermal conductivity and excellent mechanical and physical properties also at elevated temperatures. It is used as electrode material in spot, seam and butt resistance welding of low carbon steel sheets. Further it is used for manufacture of various components for resistance welding equipment. [15]

Mechanical properties of unformed material (before cold forming) were determined with tensile test, Brinell and Vickers micro-hardness were measured by measuring instrument WPM, electrical conductivity was measured by the Sigmatest instrument. Measured values for different mechanical properties for unformed material are presented below:

Tensile strength $R_m = 480 \text{ N/mm}^2$

Yield strength $R_{p0.2} = 396 \text{ N/mm}^2$

Impact toughness (ISO V-notch, 20 °C) $W_i = 169 \text{ J}$

Electrical conductivity $\sigma = 50, 1 \text{ m/}\Omega\text{mm}^2$

For determination of the influence of effective strain on the change of hardness, electrical conductivity and flow stress, the cold upsetting was used.

The cylinders of CuCrZr with initial diameter of 10 mm and height of 14 mm were lubricated with teflon foil (near frictionless conditions) and then formed by the special experimental tool for upsetting. Many experiments were done to provide the right results. After each experiment effective strain, flow stress and electrical conductivity were measured.

3. Results

Table 1 represents the values for electrical conductivity measured at specimens which were formed at different effective strain. It is obviously that electrical conductivity is decreasing with higher values of the effective strain. From starting value of 49,8 m/Ωmm² electrical conductivity is down to only 44,6 m/Ωmm² at effective strain value of 1,1. The difference in electrical conductivity between unformed specimen and the specimen formed at $\epsilon_e = 1, 1$ is more than 10%.

Table 1. Electrical conductivity measured at different rate of the effective strain.

Effective strain ϵ_e	Electrical conductivity σ [m/Ωmm ²]
0,05	49,8
0,2	49,1
0,4	47,8
0,6	46,2
0,8	45,5
1,0	44,9
1,1	44,6

Flow curve is one of the most important data for any forming process and provide us vital information about material behavior during forming process.

The measure of strain hardening must be incorporated in the consideration of more general processes. In this regard, it is assumed on the basis of sufficient agreement with experiments that the strain hardening for a particular material depends on the work per unit volume which has been expended. In our case there is an increase of

nearly 50% between initial flow stress and flow stress of maximal deformed material ($\varepsilon_e = 1, 1$). Flow stress diagram is shown on Fig. 1.

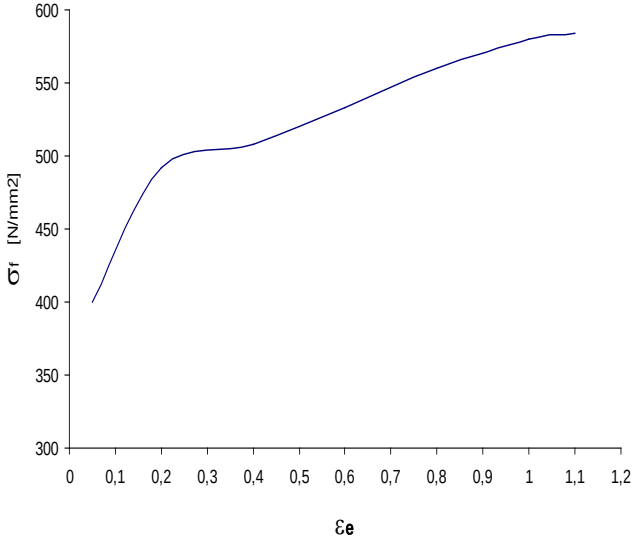


Fig. 1. Change of flow stress (σ_f) as a function of effective strain ε_e

The experimental results can also be presented in the mathematical way by using statistical methods especially regression analysis. For this reason the mathematical model for the regression analysis was chosen as written [12, 13]:

$$y = b_0 + b_1 x_1 + b_2 x_1^2 \quad (1)$$

b_0 , b_1 and b_2 are free coefficients to be determined by regression analysis; y and x_1 are parameters. The equations, calculated by regression analysis, are:

$$\sigma_f = 406,4 - 375,33 \cdot \varepsilon_e - 191,36 \cdot \varepsilon_e^2 \quad (2)$$

$$a = 50,63 + 7,44 \cdot \varepsilon_e + 0,75 \cdot \varepsilon_e^2 \quad (3)$$

By using equations (2) and (3) values of flow stress (σ_f) and electrical conductivity (a) can be calculated for every value of effective strain in the experimental area (ε_e is between 0 and 1, 1).

For determination of tensile strength, yield strength and Charpy energy the copper alloy CuCrZr was deformed by cold drawing. The specimen bar with initial diameter of 20mm has been deformed by drawing on the drawing bench with drawing speed of 20 m/min and drawing die angle $2\alpha = 28^\circ$ at room temperature.

Bars of copper alloy were deformed by drawing to six different final diameters: 19 mm, 18mm, 17mm, 16mm, 15mm and 14mm. On this way we got six different cold formed specimens (deformed bars). From deformed bars test specimens were made for tensile test to investigate the influence of strain on mechanical properties.

The results of the tensile tests are shown as a diagram on Fig. 2 which presents the change of tensile strength R_m and yield strength $R_{p0,2}$ as a function of effective strain ε_e .

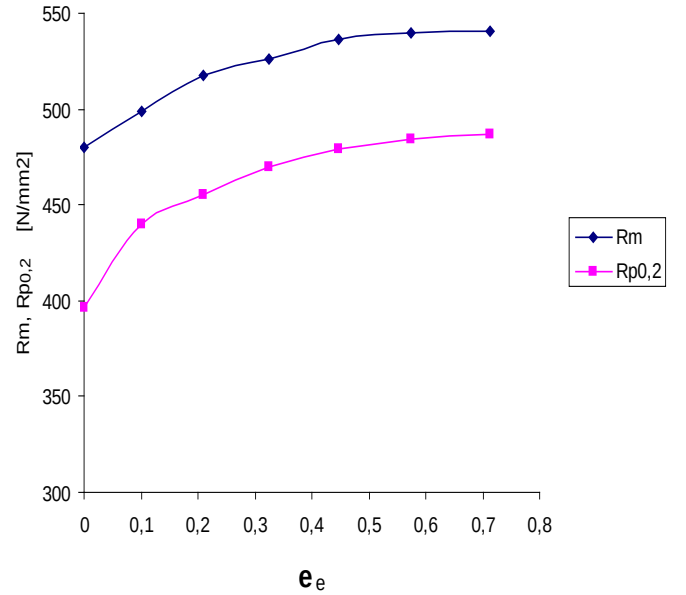


Fig. 2. Tensile strength (R_m) and yield strength ($R_{p0,2}$) as a function of the effective strain ε_e

The increase of tensile strength is very similar to that of yield strength. At the highest value of the effective strain ($\varepsilon_e = 0, 71$) the increase of tensile strength is 11% the increase of yield strength is 14% in comparing to initial values of unformed material (before drawing).

Fig. 3 presents impact toughness W_i as a function of the effective strain. Impact toughness of deformed bars was measured with Charpy test at the room temperature. The test specimens were standard ISO V-notch specimens (10mm x 10mm x 55mm and 2mm notch in the middle).

With increasing of the effective strain the impact toughness is decreasing. At the highest value of the effective strain ($\varepsilon_e = 0, 71$) the impact toughness is 12 % lower as it is before drawing. It is interesting that the decrease of impact toughness in our case is almost linear.

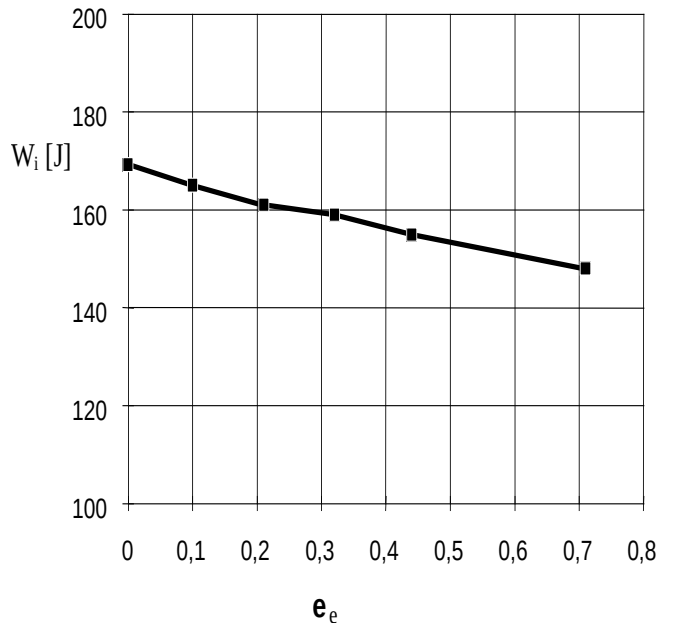


Fig. 3. Impact toughness (W_i) as a function of the effective strain (ε_e)

The experimental results can also be presented in the mathematical form by using regression analysis or any other suitable modeling methods [13] and mathematical model (1):

$$R_m = 482,46 - 165,27 \cdot \varepsilon_e + 134,43 \cdot \varepsilon_e^2 \quad (4)$$

$$Rp_{0,2} = 410,54 - 236,1 \cdot \varepsilon_e + 186,34 \cdot \varepsilon_e^2 \quad (5)$$

$$W_i = 168,87 - 35,39 \cdot \varepsilon_e + 9,37 \cdot \varepsilon_e^2 \quad (6)$$

By using equations (4) to (6) tensile strength, yield strength, and impact toughness at any value of the effective strain inside the experimental area (from $\varepsilon_e = 0$ to $\varepsilon_e = 0,71$) can be calculated.

4. Conclusion

It is well known that any cold forming process in the plastic domain of deformation introduces strain hardening characteristics in mechanical response of the material treated. The strain hardening can also be used to get workpieces whose mechanical properties are higher than for the initial material. It is also interesting from an economical viewpoint, since cheaper materials can be cold formed to get the higher mechanical properties generally obtainable in higher-grade costlier materials.

The results of measurements which are presented in our paper have shown that knowing the mechanical properties of the material to be formed and the change of properties during and after forming process is very important to predict the quality of the workpieces and for planning the right technology of the forming processes. Special mathematical models which were obtained for each measured mechanical property are especially helpful for prediction of mechanical and other properties of a cold formed alloy. In the future research we will try to determine an influence of many other parameters (such as tool speed, lubrication, strain rate, etc.) on change of mechanical properties.

5. References

1. Xing B., X He X., Wang Y., Yang H., Deng C., (2015), Study of mechanical properties for copper alloy H62 sheets joined by self-piercing riveting and clinching, *Journal of Materials Processing Technology*, Volume 216, February 2015, 28–36.
2. Mamalis A.G., Petrosyan G.L., Hambardzumyan A.F., Manolakos D.E., (2007). The effect of strain hardening in the extrusion of bimetallic tubes of porous internal layer, *Journal of Materials Processing Technology*, 181, 241 – 245.
3. Wongsan-Ngam J., Kawasaki M., Langdon T.G., (2013), A comparison of microstructures and mechanical properties in a Cu–Zr alloy processed using different SPD techniques, *Journal of Materials Science*, July 2013, Volume 48, Issue 13, 4653–4660.
4. Motaleb-Nejada P., Saeida T., Heidarzadehb, A., Darzia K., Ashjaric, M., (2014). Effect of tool pin profile on microstructure and mechanical properties of friction stir welded AZ31B magnesium alloy, *Materials & Design*, Volume 59, July 2014, 221–226.
5. Tang Y., Kang Y., Yue L., Jiao X., (2015), The effect of aging process on the microstructure and mechanical properties of a Cu–Be–Co–Ni alloy, *Materials & Design*, Volume 85, 15 November 2015, 332–341.
6. Gusel L., Anzel I., Brezocnik M, (2005), Effect of lubrication on the stress distribution in an extruded material, *International Journal of Advanced Manufacturing Techn.*, Vol. 25; 288 – 291.
7. Valiev R. Z., Raabb, G.I., Salishcheva, G.A., Kuznetsova, A.V., Stepanova, N.D. (2012), Effect of cold rolling on microstructure and mechanical properties of copper subjected to ECAP with various numbers of passes, *Materials Science and Engineering: A* Volume 554, 30 September 2012, 105–115.
8. Lange K., (1993), *Handbook of metal forming*, McGraw – Hill Book Company, N.Y.
9. Nagarajan D., Chakkinga U., Venugopal P., (2007), Influence of cold extrusion on the microstructure and mechanical properties of an aluminium alloy previously subjected to equal channel angular pressing, *Journal of Materials Processing Technology* 182, 363 – 368.
10. Murashkin M., Medvedev A., Kazykhanov J., Krokhin A., Raab G., Enikeev N., Valiev R.Z., (2015), Enhanced mechanical properties and electrical conductivity in ultrafine-grained Al 6101 alloy processed via ECAP-conform, *Metals* 2015, 5(4), 2148–2164.
11. Schuha B., Mendez-Martinb F., Völker B., Georgec E.P., Clemens H., Pippene R., Hohenwartera A., (2015), Mechanical properties, microstructure and thermal stability of a nanocrystalline CoCrFeMnNi high-entropy alloy after severe plastic deformation, *Acta Materialia*, Volume 96, 1 September 2015, 258–268.
12. Spur G., Stoeferle T., (2002), *Handbuch der Fertigungstechnik*, Band 2/2-Umformen, Carl Hanser Verlag, München.
13. Barnes J.W., (2009), *Statistical Analysis for Engineers and Scientists – a computer based approach*, The University of Texas, McGraw-Hill, New York, USA.
14. Guo Z., Sha W., (2004), Modelling of correlation between processing parameters and properties of maraging steels using artificial neural network, *Computational Materials Science* 29, 12 – 28.
15. Alizadeh A., Taheri-Nassaj E., (2012), Mechanical properties and wear behavior of Al–2wt.% Cu alloy composites reinforced by B 4 C nanoparticles and fabricated by mechanical milling and hot extrusion, *Materials Characterization*, Volume 67, May 2012, 119–128.

IMPROVING THE RELIABILITY OF INSTRUMENTS FOR MEASURING AND THERMAL CONTROL OF OBJECTS OF DIFFERENT PHYSICAL NATURE BY THE FINISH ELECTRON-BEAM PROCESSING SURFACES OF OPTICAL ELEMENTS

ПОВЫШЕНИЕ НАДЕЖНОСТИ ПРИБОРОВ ДЛЯ ИЗМЕРЕНИЯ И ТЕПЛОВОГО КОНТРОЛЯ ОБЪЕКТОВ РАЗЛИЧНОЙ ФИЗИЧЕСКОЙ ПРИРОДЫ ПУТЕМ ФИНИШНОЙ ЭЛЕКТРОННО-ЛУЧЕВОЙ ОБРАБОТКИ ПОВЕРХНОСТЕЙ ИХ ОПТИЧЕСКИХ ЭЛЕМЕНТОВ

Associate Professor Ph.D. Yatsenko I.¹, Professor dr. eng. Antonyuk V.², senior researcher dr. eng. Kyrychenko O.³, Professor dr. eng. Vashchenko V.⁴

Department of Electrotechnical Systems¹, Department of Physics⁴ - Cherkassy State Technological University, Ukraine

Faculty of instrument-making², National Technical University of Ukraine "Kiev Polytechnic Institute", Ukraine

Department of organization of technogenic-prevention work and health safety³ - Cherkassy Institute of Fire Safety named after Heroes of Chornobyl of National University of Civil Protection of Ukraine, Ukraine

E-mail: irina.yatsenko.79@mail.ru

Abstract: The optimum ranges of the electron beam parameters change (density of heat exposure and speed of movement), within which there is a substantial improvement (more than 2 ... 3 times) of the basic properties of the surface layers of the optical elements are found. The tests of the optical windows of laser rangefinders under intensive external heating and hemispherical optical fairings of IR devices at supersonic blowing by air flow and axisymmetric rotation that simulate real operating conditions, have shown that in the case of processed by electron beam optical windows and fairings it reduces the number of their destruction and increases the reliability of the devices during the operation, taking into account the impact of external-heat.

KEY WORDS: optical glass, optical ceramics, electron beam processing, elements of precision instrument-making

1. Introduction

Modern devices with optical elements for measuring and thermal control of different physical nature objects (laser rangefinders sighting systems with optical windows of the transmitting and receiving channels, IR devices with optical hemispherical fairing for homing and surveillance, etc.) in operating conditions are exposed to intense external heat (higher heating temperature and external pressure, the shock-heat in a shot and a flight and so on).

Under these conditions a variety of negative defects (cracks, bumps, depressions, nodules etc.), further development of which leads to destruction of elements (detachment, chipped, undulating surface appear) are formed on the surface and in the surface layers of the optical elements. The result is a worsening of their basic properties, reduced resistance to external mechanical and thermal stresses, which results in reduction of reliability of devices during their operation to the influence of external-heat [1 - 7].

There fore relevant is the anticipation of these adverse events during the design and manufacturing of the considered devices with optical elements. In many studies carried out by different authors in the direction [8 - 12], it was shown that one of the promising areas in removing undesirable changes in the properties of the surface layers of the optical elements is their finishing by movable electron beam. In particular, it shows the possibility of an electron beam method in the formation of the surface layers elements of the optical glass and ceramics with modified physical and chemical properties [2, 9, 10, 12].

However, there has not been established the optimum ranges of the parameters changes of the electron beam, within which there is the most significant improvement in properties of the surface layers of the elements that affect the reliability of devices during their operation.

Therefore, this paper presents the results of studies to determine the optimal ranges of change of the electron beam parameters (density of heat exposure, movement speed) that lead to the most significant improvement in properties of the surface layers of the elements of the optical glass (K8, K108, K208, and others) and ceramics (KO1, KO2 and others) and increase the reliability of devices during their operation.

2. Results and discussions

The following optimal ranges of electron beam parameters: the density of heat exposure $F_n = 7 \cdot 10^6 \dots 8 \cdot 10^8 \text{ W/m}^2$ and the moving speed $V = 5 \cdot 10^{-3} \dots 5 \cdot 10^{-2} \text{ m/s}$, within which there is the most significant improvement of the properties of the surface layers of the optical elements (more than 2 ... 3 times) are established.

Electron microscopic study of surfaces of optical glass elements (fig. 1, 2) showed that after machining the most characteristic there is the presence of various microroughness - small cracks of 0.1 ... 0.7 microns depth, fine scratches of 2 ... 5 microns length and bubbles of $10^{-3} \dots 10^{-2}$ microns size. After electron beam treatment the bubble sizes (diameters) are reduced in 2 ... 4 times on the surface elements, while other microroughness of less than 1 ... 2 microns are not observed, that is by treating the surface with an electron beam elements like "purified" small defects are eliminated. Thus, the area which is occupied by these defects decreases in 1.8 ... 2.7 times with increasing F_n from $5 \cdot 10^6 \text{ W/m}^2$ to $7 \cdot 10^7 \text{ W/m}^2$.

Study of scans of thin elements surfaces of chips before and after electron beam treatment indicates that in the first case microroughness height of 30 ... 40 nm, and in the second it is reduced to a level of 0.5 ... 1.2 nm. The following effect of an electron beam parameters on the height of the residual microscopic irregularities: an increase in the density of an electron beam heat exposure from 10^7 W/m^2 to $8,5 \cdot 10^7 \text{ W/m}^2$, for example, used in practice, the speed of its movement $V = 8 \cdot 10^{-3} \dots 5 \cdot 10^{-2} \text{ m/s}$ leads to a reduction of residual microroughness height from 3...5 to 1.0...1.5 nm (Fig. 3a) is defined.



a)

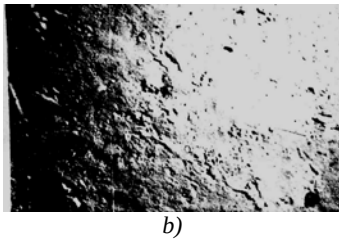


Fig. 1. An electron microscopic images of the surface of optical glass elements K8: a) - a surface after mechanical processing, $\times 3700$; b) - a surface after electron beam processing, $\times 4500$.

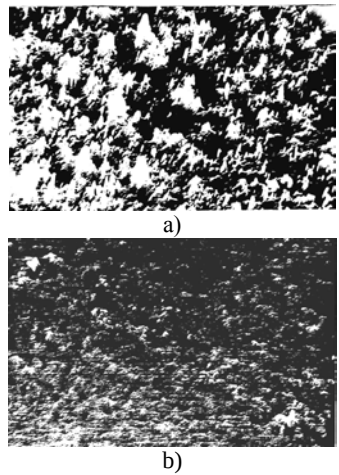


Fig. 2. The scans of the element surface of the optical glass K208: a) - a surface to electron beam processing, Y-modulation, $\times 610$; b) - a surface after electron beam processing, Y-modulation, $\times 610$.

It is found that the maximum thickness h_m of the molten layer can reach values of 250 ... 300 microns, which can exceed the maximum allowable value $h^* = 150...200$ microns, which leads to disruption of flatness and geometrical shape of the optical element (Fig. 3b). Thus h_m value depends essentially on the values of F_n and its movement speed V : an increase of F_n from $7 \cdot 10^6$ W/m² to $8 \cdot 10^8$ W/m² are used in practice, the values of V increases the melted layer thickness from 25 microns to 230 microns; increasing the speed of movement of an electron beam from 10^{-3} m/s to 10^{-2} m/s when in practice, the used values of F_n already lead to a reduction of depth in fusion from 200 microns to 30 microns.

It has been shown that exposure of an electron beam on the ceramic optical elements of ($F_n = 10^6...2 \cdot 10^7$ W/m², $V = 10^{-3}...2 \cdot 10^{-2}$ m/s) increases the microhardness of their surface depending on electron beam parameters: F_n increase from 10^6 W/m² to $1.5 \cdot 10^7$ W/m² increases the microhardness of the ceramic surface in 1.5...1.7 times, and a reduction from $1.5 \cdot 10^{-2}$ m/s to 10^{-3} m/s results an increase in the microhardness of ceramic surface in 1.3 ... 1.4 times (Fig. 4a).

It is found that the thickness of the hardened layer (Δ , microns), where there are major structural changes and it is increased the microhardness of the treated material examined for electron beam parameters that is changed in the range from 70...90 microns до 210...230 microns in thickness of processed workpieces $4...6 \cdot 10^{-3}$ m (Fig. 4b). Value of Δ also depends essentially on the electron beam parameters: increase F_n from 10^6 W/m² to $2 \cdot 10^7$ W/m² results in an increase in the thickness of the hardened layer of 1.8 ... 2.6 times, and increasing the speed of movement of the beam from $1.5 \cdot 10^{-3}$ m/s to $2 \cdot 10^{-2}$ m/s leads to a reduction in the thickness of the hardened layer in 1.7 ... 2.5 times. The presence of compressive stresses up to 25 ... 90 MPa in thin surface layers of the elements of 40 ... 60 microns depth for the central part of the processed areas (size portions $4 \cdot 10^{-2}...5 \cdot 10^{-2}$ m) in these ranges of electron beam parameters change is determined.

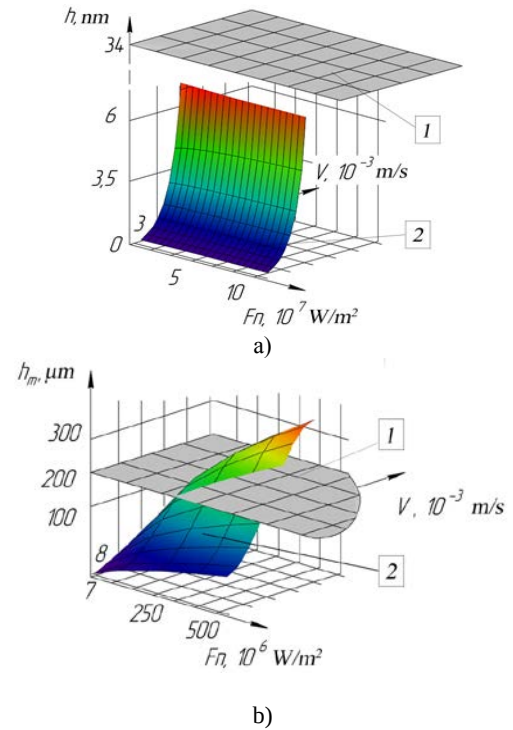
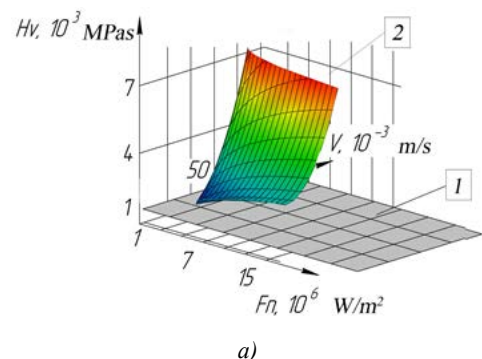


Fig. 3. The dependence of the height of the residual microroughness h (a) on the surface of the optical glass element K108 (a) and a maximum thickness of its melted layer h_m (b) from the electron beam parameters: 1 - the maximum permissible values h^* ; 2 - h_m values that were obtained when processing by an electron beam.

In addition, it was found that, after finishing electron-beam processing of the optical elements, resulting in improvement of the above properties of surface layers, there is an increase of elements resistance to external influences: increasing the critical values of the external heat flows q_n^* and t^* , the excess of which leads optical elements to fracture and failure of devices in 1.4...1.5 times for optical glasses and in 1.3...1.7 times for optical ceramics; an increase of the external pressure to 10^7 Pa reduces the values of t^* and only in 1.4 ... 1.5 times for the optical glass and in 1.3 ... 1.7 times for optical ceramics.

It was also shown that the limit values σ^* of thermoelastic stresses at different heating temperatures $T = 300...1200$ K for optical elements, processed by electron beam, in 1.7 ... 2.3 times higher for the optical glasses, in 1.8 ... 2.7 times - for optical ceramics.

The test analysis of the optical ceramics elements hardened by electron beam, for resistance to external mechanical impacts according to standard techniques (it was defined critical height H_{kp} from which a steel ball of diameter $d = 4 \cdot 10^{-3}...5 \cdot 10^{-3}$ m, freely falling, destroys the element surface, Fig. 5) showed (for $F_n = 10^8...5.5 \cdot 10^8$ W/m², $V = 10^{-2}...5 \cdot 10^{-2}$ m/s) that for unprocessed elements - $H_{kp} = 0.18...1.1$ m, and for processed - $H_{kp} = 0.37...1.35$ m.



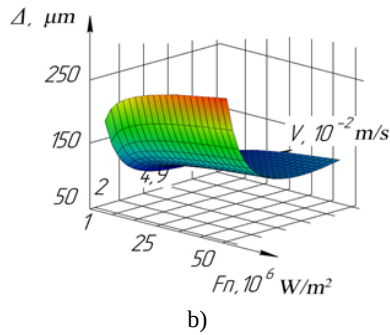


Fig. 4. The dependence of the surface microhardness H_v (a) of an optical ceramics element of KO1 (a) and the thickness of its hardened layers Δ (b) of the electron beam parameters: 1 - unprocessed surface; 2 - the electron beam processed surface.

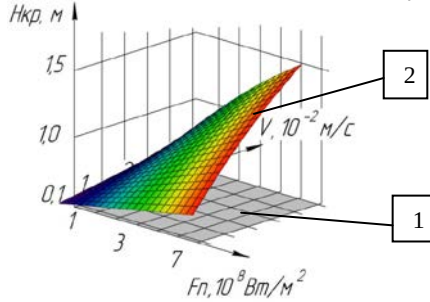


Fig. 5. The dependence of critical value H_{kp} for the optical ceramics elements of KO2 from the electron beam parameters: 1 - unprocessed surface; 2 - surface-processed by electron beam.

Thus, the finish electron beam processing of optical elements leads to an improvement in their surface layer properties, which ultimately increases their resistance to external mechanical and thermal impacts, and can enhance reliability of devices during their operation under conditions of external-heat.

Indeed, carried out tests of optical windows of laser rangefinder under intense external heating and hemispherical fairings IR devices at supersonic blowing air flow and axisymmetric simulating actual operating conditions have shown that in the case of processed by electron beam input windows and fairings in the zones of maximum external-heat (most dangerous areas on their surfaces where the fairings may undergo to destruction) occurs in 1.7 ... 2.3 times less damage than unprocessed windows and fairings (Table 1).

Table 1

The effect of electron beam processing of the optical windows surfaces of laser sights and hemispherical fairing of IR devices targeting and observation on the number of their destruction $\bar{k}^*$ (%) depending on the parameters of the external-heat (heating rates V_1 (K/s) for windows from optical glass K8; airflow speed V_2 (m/s) for the fairings from optical ceramics KO2)

Input window $V_1, K/s$	$\bar{k}, \%$	
	Before electron-beam processing	After electron-beam processing
100...200	40...50	20...30
200...300	50...60	30...40
300...400	60...70	40...50

Fairing $V_2, K/s$	$\bar{k}, \%$	
	Before electron-beam processing	After electron-beam processing
$5 \cdot 10^2 \dots 10^3$	30...40	10...20
$10^3 \dots 1.5 \cdot 10^3$	40...60	20...40
$1.5 \cdot 10^3 \dots 2 \cdot 10^3$	60...80	30...50

^{*)} Note. $\bar{k} = \frac{k}{k_0}$, where k_0, k – the total number of test input

windows and fairings and their number accordingly subjected to destruction. The angular speed of an axisymmetric rotation of fairings in this range of variation (up to $4 \cdot 10^3$ rad/s) is not affected much the number of their destruction.

The coefficient of reliability as a criterion of laser rangefinders performance at different speeds of external heating, as well as IR-devices at supersonic air flow blowing is determined by the following formula [12]:

$$W(V_i) = 1 - \frac{N(V_i)}{N_0}, i = 1, 2, \quad (1)$$

where $W(V_i)$ - the probability of working capacity preserving of the considered devices under the external heat conditions; $N(V_i)$ - the number of devices that deny for the given parameters of external-heat (destruction of the input windows and fairings was taken as the failure of the device as a whole); N_0 - the total number of input windows and fairings which are tested.

The calculations using formula (1) revealed that the increase in the heating rate of the input windows of laser rangefinders (from 100 K/s to 400 K/s) and blowing by air flow fairings of considered IR devices (from $7 \cdot 10^2$ m/s to $2 \cdot 10^3$ m/s), implemented in practice in terms of actual operation, lead in the case of their finish electron-beam processing of surfaces to the increase of these devices reliability in 1.3 ... 1.9 times (Fig. 6, 7).

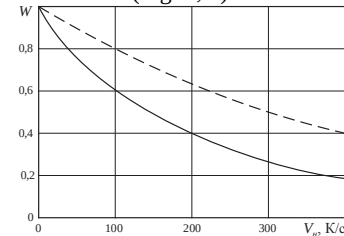


Fig. 6. The dependence of the probability of failure-free operation of laser sights in external heat conditions from the external heating rate of the optical windows: — — optical windows, not processed by electron beam; - - - optical windows, which surface is processed by electron beam (the beam parameters $F_n = 5 \cdot 10^8$ W/m², $V = 5 \cdot 10^{-3}$ m/s).

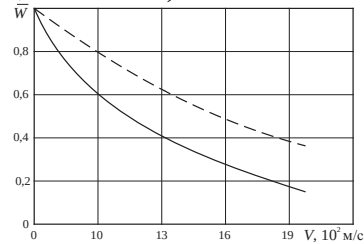


Fig. 7. The dependence of the probability of failure-free operation of IR devices under terms of the shot and the flight on the supersonic airflow speed by air flow of their hemispherical fairings: — — fairings, not processed by electron beam; - - - fairings processed by electron beam (beam parameters $F_n = 2 \cdot 10^7$ W/m², $V = 10^{-3}$ m/s).

3. Conclusions

1. It is found that in the result of finish electron-beam processing of element surfaces of the optical glass (K8, K108, K208) and ceramics (KO1, KO2) for optimal ranges of change of the electron beam parameters (density of heat exposure $F_n = 7 \cdot 10^6 \dots 8 \cdot 10^8$ W/m² and the speed of movement $V = 5 \cdot 10^{-3} \dots 5 \cdot 10^{-2}$ m/s) there is a significant improvement in the properties of their surface layers:
- various negative defects disappear on the surface (scratches, fine bubbles, cracks, etc.) remaining after the standard machining processing, it becomes atomically smooth;

- height of residual microscopic irregularities on the surface is reduced from 30 ... 40 nm to 0.5 ... 1.2 nm, and the thickness of the molten layer is 250 ... 300 microns, which may exceed the maximum permissible values of 150 ... 200 microns, not breaking the flatness and geometric forms of the elements;
- the surface micro-hardness increases in 1.5...1.7 times, the thickness of the hardened layers reaches 210 ... 230 microns with compressive stresses up to 25 ... 90 MPa.

2. It is shown that in a result of improving the properties of surface layers of the elements after their electron beam processing, the optical elements resistance increases to external mechanical and thermal impacts:

- the critical value of the external heat fluxes and the times of their actions increases in 1.5 ... 4 times, that leads to the destruction of the elements; the increase of external pressure to 10^7 Pa reduces the listed critical values in 1.3 ... 1.7 times;
- increase in 1.7 ... 2.7 times the maximum permissible values of thermal stress in the temperature range 300 ... 1200 K, the excess of which leads to the destruction of the elements;
- the critical height of a steel ball fall on the surface of elements, leading to their destruction, rise from 0.18 ... 1.1 m to 0.37 ... 1.35 m.

3. It is found that after finishing electron-beam processing of the optical elements, resulting in improved properties of their surface layers and increasing the resistance of the elements to external influences, with increasing heating rates of the input optical windows of the laser rangefinders (up 400 K/s) and the speed of air blowing flow (up $2 \cdot 10^3$ m/s) and axisymmetric rotation (angular speed of up to $4 \cdot 10^3$ rad/s) fairings of IR devices, increasing their reliability in 1.3 ... 1.9 times.

4. References

1. Vashchenko V. A., Kotelnikov D. I., Lega Y. G., Krasnov D. M., Yatsenko I. V., Kirichenko O. V. Teplovye protsesy pri elektronnoi obrabotke opticheskikh materialov i ekspluatatsii izdelii na ich osnove (Thermal processes in the electronic processing of optical materials and use of products based on them) Kiev: Naukova Dumka, 2006, 368 p.
2. Vashchenko V. A., Yatsenko I. V., Lega Y. G., Kirichenko O. V. Osnovy elektronnoi pbrobky vyrobiv z optychnykh materialiv (The basics of electronic processing of optical materials) Kiev: Naukova Dumka, 2011, 562 p.
3. Yatsenko I., Antonyuk V., Bondarenko M., Vashchenko V. Influence of parameters by electronic ray on properties of superficial layers of optical elements of exact instrument-making // International journal for science and innovations for the industry "Innovations in discrete productions", ISSN 114-8907, YEAR III, ISSUE 1/2015, Sofia. – P. 13 – 15.
4. Yatsenko I. V., Antonyuk V. S., Vashchenko V. A. Упреждение возможных разрушений оптических обтекателей ИК-приборов в условиях выстрела и полета (Anticipation of possible damage fairings optical infrared devices in a shot and the flight) // Monthly scientific-technical and industrial journal "Nanoengineering", 2015. – № 12(54). – P. 26 – 31.
5. Yatsenko I. V., Antonyuk V. S., Vashchenko V. A. Попередження можливих руйнувань оптичних елементів точного приладобудування в умовах зовнішніх термодій (Prevention of possible damage optical elements precision instrument in terms of external thermal action) // Journal of Nano- and Electronic Physics, 2016. – Volume 8. – № 1. – P. 01027 – 01032.
6. Yatsenko I. V. Experimental and statistical models of impact determination of the electron beam parameters on surface layers properties of optical elements in precision instruments building // "Pratsi. Odes'kyi politechnichnyi universytet", 2016. – Issue 1(48). – P. 63 – 69.
7. Yatsenko I., Antonyuk V., Kiritchenko O., Vashchenko V. Improvement of technical and operational characteristics of devices with optical elements by preliminary electron beam treatment of their surface // International journal for science and innovations for

- the industry "Machines. Technologies. Materials", ISSN 1313-0226, YEAR X, ISSUE 6/2016, Bulgaria. – P. 47 – 50.
8. Dudko G. V., Kulov, S. K., Rose Y. A., Maksimova N. G. Issledovanie elektronno-luchevykh protsessov v sozdanii bazovykh tekhnologii ELEFP (Investigation of electron-beam processes in the creation of basic technologies ELEPP) *Elektronnaya promyshlennost*, 1991, Vol. 1, P. 41 – 45.
 9. Vashchenko V. A., Dubrovskaya G. N., Kanashewich G. V., Pozdeev S. V. Opticheskie svoistva podlozhek OIS iz stekla posle nizkoenergeticheskoi elektronno-luchevoi obrabotki (Optical properties of substrates OIC of glass after low-energy electron-beam processing). Proceedings of the 3rd International Symposium vacuum technology and equipment, Kharkiv, 22 – 24 September 1999, P. 115 – 118.
 10. Dubrovskaya G. N., Kanasevich G. V., Vashchenko V. A., Kotelnikov D. I., Yatsenko I. V. Poluchenie funktsyonalnykh sloev v opticheskom stekle i keramike metodom elektronnoy obrabotki (Obtaining functional layers in the optical glass and ceramics by means of electronic processing). Collection of reports of International scientific-practical Symposium "Functional coatings on glass", Kharkiv: NTC HFTI "Konstanta", 2003, P. 135 – 137.
 11. Yatsenko I. V. Дослідження залежностей енергетичних характеристик СЕП від його керованих параметрів при впливі на виробі мікрооптики і інтегральної оптики (Investigation of dependence of the BEB (belt electron beam) energy performance of its controlled parameters when exposed to mikrooptyky products and integrated optics) // "Pratsi. Odes'kyi politechnichnyi universytet", 2009. – Issue 2(32). – P. 143 – 149.
 12. ДСТУ 2860-94. Надійність техніки. Методи оцінки показників надійності за експериментальними даними. (Reliability engineering. Methods for assessing the reliability indices for the experimental data.)

STUDY OF EFFECT OF INITIAL AND SUBSEQUENT HEAT TREATMENT OF CONSTRUCTIONAL STEELS ON PROPERTIES OF JOINT WELDS PRODUCED BY ELECTRON BEAM WELDING

Исследование влияния предварительной и последующей термической обработки конструкционных сталей на свойства сварных швов, получаемых с помощью ЭЛС

Engineer Izyumov Artem A., Engineer Artem Gubko D., Physical-technical Institute of the National Academy of Sciences of Belarus- Minsk, Belarus

E-mail: zero30051992@mail.ru, trampoff@mail.ru

Absract:

The effect of modes of electron beam welding on geometry of joint welds of constructional steels has been analyzed using steel 40X as an example. Microstructure and microhardness distribution in joint welds have been investigated. Necessity of preheating and subsequent heat treatment of metal in order to avoid hot cracking at electron beam welding has been determined.

KEYWORDS: EBW, CARBON STEEL, CONSTRUCTIONAL STEEL

1.Introduction

There is a need in production of joint welds by electron beam welding (EBW) of parts made of constructional carbon steels and alloyed steels that are considered to be conditionally weldable and hardly weldable materials. The chemical composition analysis of these steels has shown that some of them have a strong tendency towards origination of welding defects such as cold and hot cracking. The main method of cold cracking prevention is initial heating that can be successfully performed at EBW, first of all, due to a wide range of opportunities of electron beam heating. In order to prevent hot cracking, the main cause of which being low-melting sulfides, modifying agents that bind sulphur into high-melting compounds are used in electric-arc welding methods.. The modifying agents are added into a molten weld pool together with filler materials. However, there is no such opportunity at deep alloying EBW that does not use grooving and fillers, which is the main economic advantage of this method as compared to electric-arc welding methods. This makes search and development of technological methods of hot cracking prevention urgent.

2.Objective

The objective of this work has been finding of an optimal initial state of material, its initial and subsequent heat treatment modes in order to produce high-quality joint welds in constructional steels by means of EBW. The work presents the research results on the effect of an initial structure, initial and subsequent heat treatment modes and EBW parameters on geometry, structure, mechanical properties and chemical composition of joint welds in constructional carbon steels and alloyed steels.

3.Results

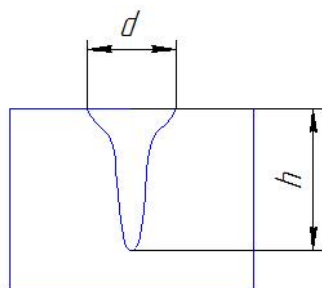


Fig. 1 – Schematic representation of the joint weld depth and width

The effect of EBW modes on geometry of joint welds of 40X constructional steels has been analyzed. Microstructure and microhardness distribution in joint welds have been investigated.

Electron beam welding of samples made of constructional steels has been performed in vacuum at a residual pressure of $5 \cdot 10^{-3}$ Pa. Welding modes for 40X steel have been as follows: an accelerating voltage of 60 kW, a beam current of 110 mA, a focusing current of 695 mA, a welding rate of 10 mm/s. Welding of the samples has been performed without preheating.

Geometry of the joint welds produced by EBW of the given constructional steels has been analyzed. The joint weld geometry is characterized by the following size factors: the depth h and the width d (Fig.1). The joint weld depth is defined as the longest distance between a joint weld surface and a point of maximum weld penetration of a base metal. The joint weld width is the maximum distance between visible weld lines at a transverse macrosection. Variation of the joint weld geometry (depth and width) for steel 40X depending on welding modes is presented in Table 1. The joint welds obtained by EBW of steel 40X samples have a depth of 9-12 mm and a width of 7-8 mm.

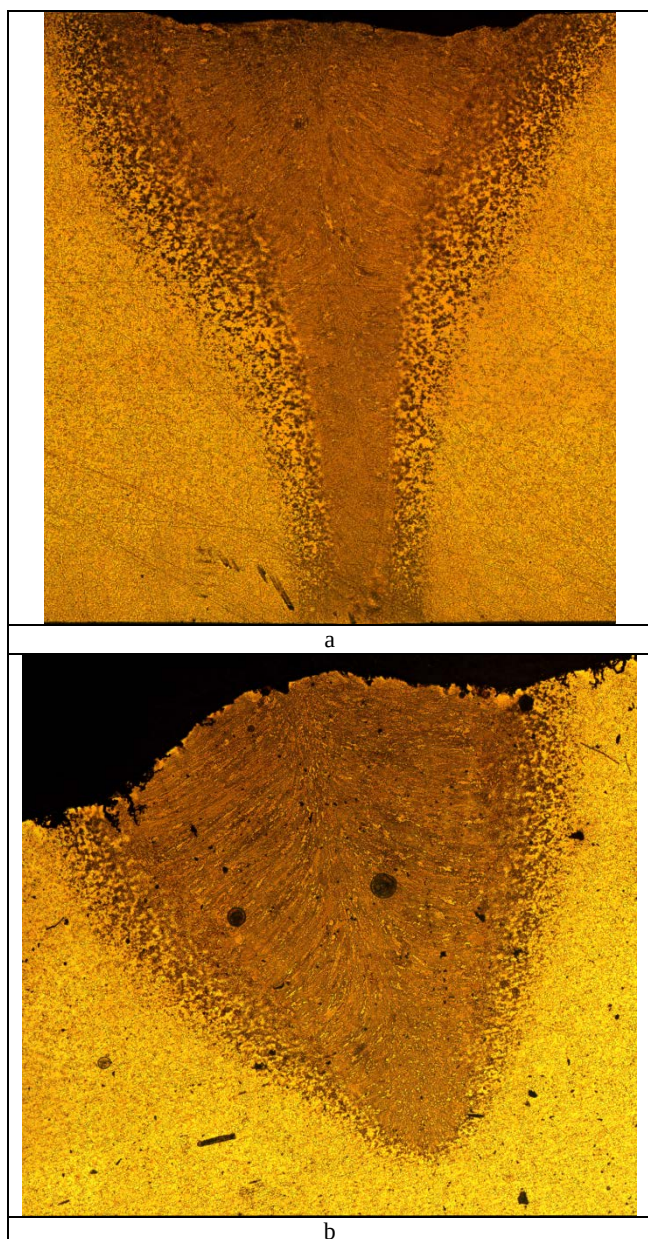
For metallographic tests on the joint welds produced by EBW samples with two planar parallel surfaces have been cut off using Micracut 151, a precision cutting-off machine. After that the samples have been exposed to grinding, polishing and etching. In order to determine the structure of 40X samples a mixture of 4% solution of nitric acid and ethyl alcohol has been used as an etching agent. Microstructure has been investigated using MI-1 microscope equipped with a CCD camera.

Study of microhardness of joint welds has been carried out using PMT-3 device. Loading on the penetrator has been 100g for steel 40X.

Joint weld parameters			EBW modes	
Sam- ples	Depth, mm	Width, mm	Focusing current, mA	Beam current, mA
1	8.0	5.4	650-660	100
2	6.7	4.9	650-660	80
3	3.9	5.5	660-670	80
4	6.8	3.8	633-643	90
5	6.5	3.8	633-643	90
6	5.0	3.3	633-643	95
7	5.5	4.2	633-643	100
8	4.0	4.4	633-643	70
9	4.2	4.7	633-643	50
10	5.3	5.3	633-643	60

Table 1 – Variation of the joint weld geometry depending on EBW modes

Fig. 2 presents the microstructure of 40X joint welds in the test samples 1 and 7 after EBW. This figure shows that there are no cracks in joint welds. In sample 7 there are some pores.



a is the sample 1, b is the sample 7
Fig. 2 – Microstructure of 40X joint welds produced by EBW

Fig. 3,a shows the steel 40X microstructure: fine-grained, ferrite with small dark perlite inclusions. The microhardness is 1.1-1.2 GPa (Fig.4). Fig. 3,b shows ferrite-perlite structure of steel 40X. The ferrite microhardness (light phase) is 1.3-1.6 GPa, the perlite microhardness (dark phase) is 1.9-2.3 GPa.

Fig. 5 shows the microstructure of the joint weld of 40X sample obtained by EBW. The microhardness of the joint weld metal is 1.3-2.1 GPa.

Fig. 5,b shows the structure of the joint weld using a 40X sample as an example. The joint welds have dendritic structure, dendritic crystals being elongated in the direction of heat rejection. Fig.6 shows microhardness distribution in 40X joint weld. Due to a great difference between the microhardness values of the light and the dark phases measurements have been taken in terms of the dark phase. The microhardness of the given phase in the joint weld zone is 2.8-3.0 GPa, which slightly exceeds the microhardness of the base metal. For the light phase the microhardness is 5.2-5.9 GPa. In the course of EBW quenching struc-

tures are formed, which leads to a great increase in the hardness of the joint weld material as compared to the base metal and serves as a disadvantage in terms of strength balance of separate parts of the welded structure.

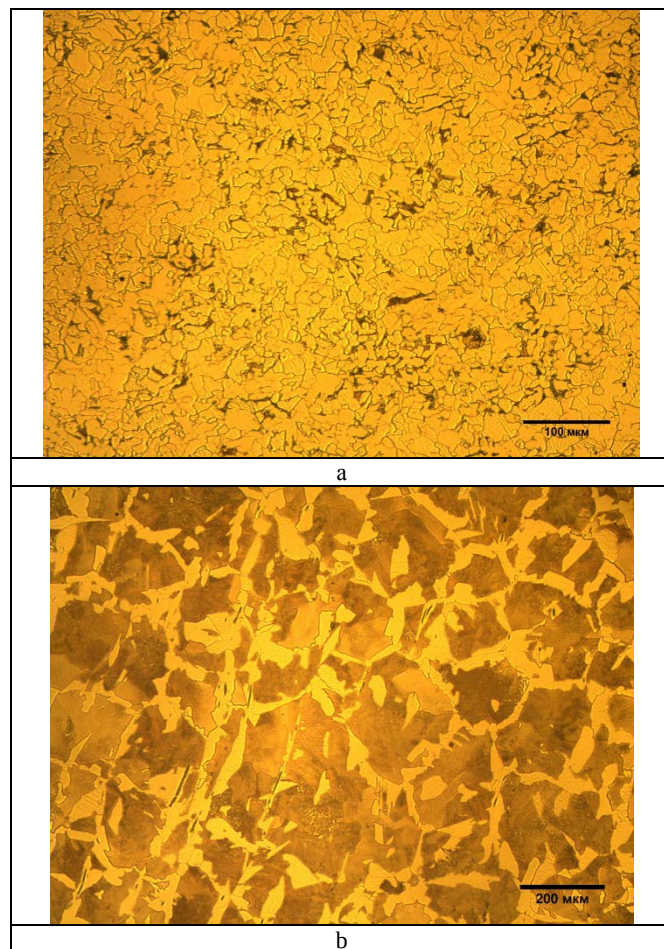


Fig. 3 Microstructure of the constructional steel 40X (a) and (b) in initial state

A heat-affected zone (HAZ) is small (0.6-1.5 mm) for 40X samples therefore it should not have a great effect on the joint weld strength. The microstructure of steel 40X in HAZ after EBW without preheat is shown in Fig.7.

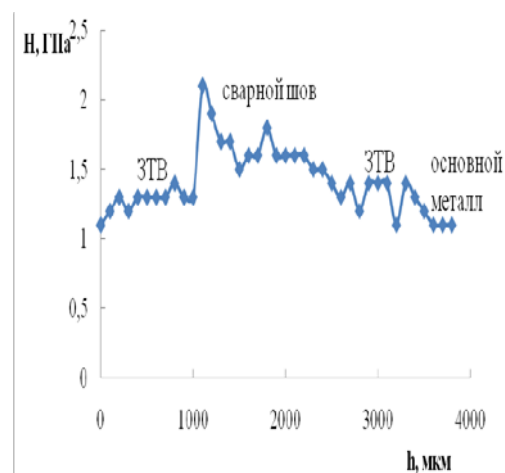


Fig. 4 – Microhardness distribution in 40X joint weld produced by EBW

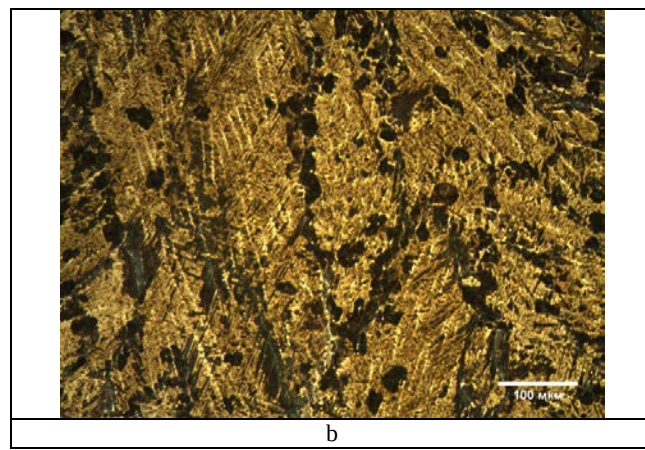
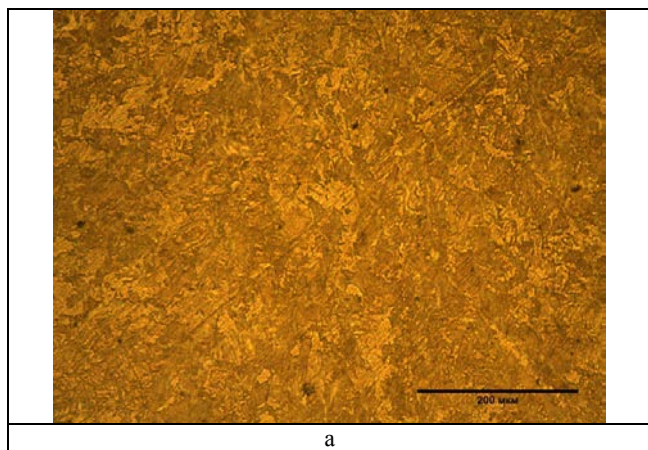


Fig. 5 – Microstructure of 40X joint welds obtained by EBW without preheat treatment (a) and (b)

The microhardness of the dark phase in HAZ is 2.1-3.0 GPa and the microhardness of the light phase is 1.3-1.5 GPa.

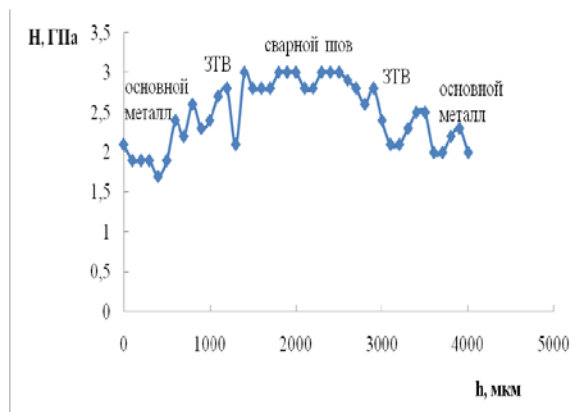


Fig. 6 – Microhardness distribution in the joint weld made of steel 40X obtained by EBW

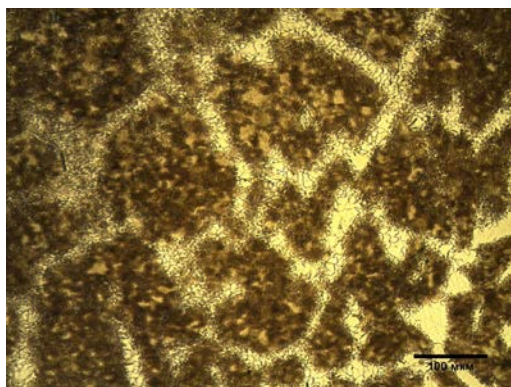


Fig. 7 – Microstructure of steel 40X in HAZ after EBW without preheating

4. Conclusions

Thus, in order to prevent formation of quench structures, which leads to an increase in microhardness of constructional steels after EBW, one needs to carry out preheat treatment and subsequent heat treatment of samples.

5. Literature

1. NN Rykalin - "Fundamentals of electron beam processing of materials", - Engineering, Moscow, 1978, 378 p.
2. NN Rykalin -, " Laser and electron beam processing of materials", - Engineering, Moscow, 1985, 289 p.
3. OK. Nazarenko - "Electron-beam welding", - Engineering, Moscow, 1985, 306 p.

A REVIEW OF RESIDUAL STRESS MEASUREMENTS BY HDM AND OPTICAL TECHNIQUES

M.Sc.Barile C. PhD¹, Prof. Casavola C. PhD¹, M.Sc. Pappalettera G. PhD¹, Prof. Pappalettera C.¹
Dipartimento di Meccanica, Matematica e Management, Politecnico di Bari, Italy¹
casavola@poliba.it

Abstract: In this paper a review of progresses occurred along the years in measuring residual stresses by optical methods is presented. These methods allow to implement the hole drilling procedure for residual stress profile measuring, without applying the strain gage rosette. This approach presents several advantages such as easier and cheaper preparation of the test beside the possibility to avoid eccentricity issues and to increase the amount of available data in view of the fact that each pixel can be considered as a measure point. In particular the evolution of the Electronic Speckle Pattern Interferometry (ESPI) technique will be presented showing how set up, methodologies and calculation approaches have developed along the last three decades.

Keywords: ESPI. RESIDUAL STRESS, HOLE DRILLING, OPTICAL METHODS

1. Introduction

The stress field existing in some materials without application of an external source of stress, such as loads or thermal gradients, is known as residual stress. These residual stresses (RS) are generated in almost all manufacturing processes such as machining, grinding, forming, rolling, casting, forging, welding, heat treatment, etc. or may occur during the life of structures. The hole drilling method (HDM) is one of the most widely used techniques for measuring residual stresses. This technique consists in the localized removal of stressed material and in measuring the strain field consequent to the relieved stresses. The hole drilling method

using strain gauge rosettes is a consolidated approach for stress determination and it follows the ASTM test standard. Even though strain gauges are usually used to measure these displacements, they have some disadvantages: the specimen surface has to be flat and smooth so that the rosettes can be attached, the surface of the material has to be accurately prepared, the hole has to be drilled exactly in the center of the rosette in order to avoid eccentricity errors, and time and costs associated with installing rosettes are consistent. Furthermore the amount of available data is limited: for each measurement, only three discrete readings are available (six in the case of some special rosettes), just sufficient to fully characterize the in-plane residual stresses. Due these considerations several attempts to replace extensimetric measurements by optical ones have been done along the years. For example the use of moiré interferometry for strain determination in RS measurements by HDM was investigated in many situations since McDonach et al. [1]. However, bonding a grating can also be time consuming. The feasibility of using holographic interferometry was shown by Antonov [2]. More recently Hung et al. [3] have used shearography in conjunction with a small ball indentation to determine RS. Also the possibility to release residual stresses by using local heat treatment, combined with electronic speckle pattern interferometry was attempted by Pechersky et al. [4] and more recently repeated on aluminum alloys in [5]. However the most explored

approach consists in combining ESPI with incremental holedrilling; the basic idea is to adopt the same procedure for RS measurement as described in ASTM E837 but replacing data obtained by the rosette with data obtained by speckle pattern. Speckle interferometry approach, in fact, is based upon the observation that whenever a coherent beam of light shines on a surface a random intensity pattern is produced as a consequence of the interference of the light diffused by surface itself. Displacements of the surface introduce changes in the local phase. Having this in mind it is easy to understand that if an hole is drilled in a material and stresses are relaxed speckle patterns change and if the speckle pattern is subtracted from a reference pattern correlation fringes are obtained as those shown in Fig.1.

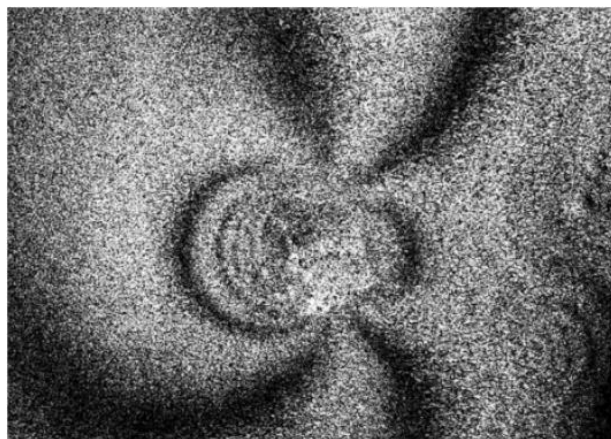


Fig.1 Example of ESPI correlation fringes obtained during the hole-drilling process. Fringes are obtained by subtracting the speckle pattern recorded at a given drilling increment from the reference pattern recorded before starting the drilling procedure. Fringes represent the loci of points of isodisplacement along the direction of the sensitivity vector

In this paper the evolution of the ESPI-HDM technique along the years is presented showing that systems have become increasingly compact and easy to operate, calculation methods have become more robust and faster and the field of application of the technique has increased more and more.

2. *Origin of ESPI-HDM*

Pioneering works in the adoption of ESPI combined with Hole Drilling methods are those of Furgiuele et al.[6]. The optical set-up adopted allowed to determine three components of the displacement in the plane of the specimen and two oblique to the plane. In order to verify the reliability of the method the system was tested on a steel specimen on which a well known stress state was introduced. The centers of the fringes were detected manually that is to say that it was a task of the user to track them on the images and to assign them the proper order of fringe. This allowed to determine the displacement on the pixel along the fringes and the to obtain stresses based upon calibration coefficients connecting the stress state to the displacement occurring as a consequence of the drilling procedure. In spite of the complexity of the optical configuration adopted and of the difficulties in speckle pattern elaboration authors obtained very promising results that paved the way to further developments. Analogous results, in terms of accuracy, were obtained two years later in [7] where, instead of a CCD camera as a recording media, photographic emulsions were adopted.

3. *Development of the technique*

Attempts to simplify the optical system with respect to pioneering works were firstly done in [8] where a system based upon a couple of optical fibers was used to implement a double Lendeertz configuration showing potentialities of this technique to be implemented in a easy to operate set-up. A similar system will be also used later for industrial application such as RS measurement in CD disc [9]. A simplified set up was also adopted later where an ESPI out-of-plane interferometer was built however, in that case, the chemical etching procedure was used instead of hole drilling to get stress relaxation along the depth. In the direction of implementing the technique in a robust a portable device it is noticeable the work done in [10], in this paper by the use of a conical mirror, an optical configuration was obtained so that the sensitivity vector is directed along the radius for each point of the analyzed specimen. The system was also tested on the field by measuring residual stresses on a pressure vessel while the same interferometric configuration was adopted in combination with indentation instead of hole drilling in [11] even if a numerical model for quantitative evaluation of RS is missing. Very huge work from the side of system development, data analysis development and automation, error sources evaluation and results validation was done in the series of papers [12-15]. The system described in those papers is quite compact; the sample is illuminated just from one side by an optical fiber while a reference beam is sent directly to the camera CCD by a second optical fiber. A database of finite element solutions was built allowing to determine surface deformation for each combination of Young's modulus and Poisson's ratio, hole geometry and stress state. Full field least square technique was implemented to determine the stress state as the combination of σ_x , σ_y and τ_{xy} that minimizes the differences between the measured displacements and the modelled ones. The algorithm allowed also to take into account the rigid body motion that can occur during the

measurement. Furthermore some sources of errors connected with the measurement such as the error on the determination of the illumination and observation angles or in the determination of the pixel size are taken into account. Further work in this sense has been done later on in [16] where effects of drilling parameters are considered for aluminum and stainless steel or in [17] where analogous analysis is carried out for Titanium grade 5. In [18-19] other sources of errors are considered such as the extension of the analysis area that is to say the effective region of the acquired interferogram that will be used for the analysis. In [20] was explored, with a good success, the possibility to perform remote drilling operation that means to afford issues connected with replacement of the sample and consequent fringe decorrelation. The issue was overcome by using a kinematic mount with two pins and two bolts and by implementing rigid body correction algorithms. Optimization of the entire measurement processes are analyzed in [21] by considering the problem of full exploitation of all available data and in [22] by considering the problem of the choice of the number and distribution of drilling steps.

4. *Recent Progresses*

In the last decade the number of works where hole drilling method an ESPI are used in combination to measure residual stresses has increased very much with applications ranging from measurement on submerged arc welded parts [23], TIG welded structural elements [24], FHPP welded part [25] etc.. At the same time some alternatives approaches also started to be attempted, for example in [26] incremental grooving was used instead than drilling while in [27-28] cross slitting and dual-axis ESPI were introduced demonstrating that this configuration gives better results with respect to the determination of the shear stress profile. Most recent works are devoted to the improvement of calculation methods; in [29] the integral method for stress computation in incremental hole drilling was modified so that the speckle image recorded at each drill increment is not correlated with the initial reference state but with the image obtained at the previous step. The matrix that rules the problem in such a case connecting incremental strain to stresses turns out to be diagonally dominant so that all the system is better conditioned and error amplification is reduced.

5. *Final Considerations*

Literature review clearly displays how the use of ESPI in combination with hole-drilling method has greatly developed along the years. Technological evolution in terms of smaller, cheaper and higher resolution CCD camera as well as smaller and higher quality laser sources allows now to obtain very robust and compact setup. At the same time calculation algorithm have been refined along the years and a series of tools have been introduced so that fringe analysis can be considered to be a semi-automated process that can be quite easily managed also by a trained but not expert operator. Due to these considerations technology appears to be mature as it is also witnessed by the presence of commercial systems available on the market and based upon this approach. It

is easy to foresee that this kind of approach will be subjected to further development and spread. At the same way it can be speculated that new research will be done on the topic in the next years for example in the direction to extend its application to non-isotropic materials or in the direction to compare this approach with a more recent one based upon detection of displacement fields by Digital Image correlation.

6. References

- [1] A. McDonach J. McKelvie, P. MacKenzie and C.A. Walker, *Experimental Techniques* 7, 20–24 (1983).
- [2] A. Antonov, *Welding Production* 30, 41-43 (1983).
- [3] Y.Y. Hung and H. Ho, *Materials Science and Engineering R49*, 61-87 (2005).
- [4] M.J. Peckersky, R.F. Miller and C. S. Vikram, *Optical Engineering* 34, 2964-2971 (1995).
- [5] C. Barile, C. Casavola, G. Pappalettera and C. Pappalettere, *Strain* 49, 393-398 (2013).
- [6] F.M. Furgiuele, L. Pagnotta and A. Poggialini, *Journal of Engineering Materials and Technology* 113, 41-50 (1991).
- [7] S.T. Lin, C.T. Hsieh and C.P. Hu, *Experimental Mechanics*, 141-147 (1993).
- [8] A. Asundi and J. Zhang, “Industrial applications of residual stress determination using 2-D in-plane sensitive fibre ESPI and hole drilling” in *Proceedings of Conference on Optical Engineering for Sensing and Nanotechnology. Proceedings of SPIE 3740*, 78-81 (1999).
- [9] I. H. Lira, C. Vial and K. Robinson, *Measurement Science and Technology* 8, 150-157 (1997).
- [10] A. Albertazzi, C. Kanda, M. R. Borges and F. Hrebabetzky, “A radial in-plane interferometer for ESPI Measurement”, in *Laser Interferometry X: Techniques and Analysis* (M. Kujawinska et al. Eds.). *Proceedings of SPIE 4101*: 77-88 (2002).
- [11] R. Suterio, A.G. Albertazzi and M.A.M. Cavaco, “Preliminary Evaluation: The indentation method combined with a radial interferometer for residual stress measurement”, in *Proceedings of the SEM Annual Conference and Exposition on Experimental and Applied Mechanics*, Charlotte (NC), USA (2003).
- [12] M. Steinzig and E. Ponslet, *Experimental Techniques*, May/June 43-46 (2003).
- [13] E. Ponslet and M. Steinzig, *Experimental Techniques*, July/August 1-5 (2003).
- [14] E. Ponslet and M. Steinzig, *Experimental Techniques*, September/October 45-48 (2003).
- [15] M. Steinzig and T. Takahashi, *Experimental Techniques*, November/December 59-63 (2003).
- [16] M. Steinzig, D. Upshaw and J. Rasty, *Experimental Mechanics* 54, 1537-1543 (2014).
- [17] C. Barile, C. Casavola, G. Pappalettera and C. Pappalettere, *Measurement* 48, 220-227 (2014).
- [18] C. Barile, C. Casavola, G. Pappalettera and C. Pappalettere, *The Scientific World Journal* 2014, 1-7 (2014).
- [19] C. Barile, C. Casavola, G. Pappalettera and C. Pappalettere, “Overview of the Effects of process parameters on the accuracy in residual stress measurements by using HD and ESPI”, in *Proceedings of the SEM Annual Conference and Exposition on Experimental and Applied Mechanics* edited by Society for Experimental Mechanics (2016).
- [20] A. Baldi and P. Jacquot, “Residual stresses investigations in composite samples by speckle interferometry and specimen repositioning” in *Proceedings of Speckle Metrology 2003. Proceedings of SPIE 4933*, 141-148 (2013).
- [21] A. Baldi, *Journal of Engineering Materials and Technology* 127, 165-169 (2005).
- [22] D. Stefanescu, C.E. Truman, D.J. Smith and P.S. Whitehead, *Experimental Mechanics* 46, 417-427 (2006).
- [23] K.S. Kim, S. B. Choi, J.H. Lee, S.M. Park, B. I. Kim, N. H. Lee, C. H. Lee and M. Woo, *Key Engineering Materials* 324-325, 859-862 (2006).
- [24] L.M. Lobanov, V. A. Pivtorak, V.V. Savitsky and G.I. Tkachuk, *The Paton Welding Journal* 1, 24-29 (2006).
- [25] M.R. Viotti, A. Albertazzi, *Optical Engineering* 10, 101905:1-8 (2013).
- [26] G. Montay, O. Sicot, A. Maras, E. Rouhaud and M. Francois, *Experimental Mechanics* 49, 459-469 (2009).
- [27] G.S. Schajer and Y. An, *Experimental Mechanics* 50, 169-177 (2010).
- [28] G.S. Schajer and M. Steinzig, *Journal of Engineering Materials and Technology* 132, 011007-1-011007-5 (2010).
- [29] G.S. Schajer, T.J. Rickert, *Experimental Mechanics* 51, 1217-1222 (2011).

THE POSSIBILITY OF USING WASTE MOLD SAND FOR ADSORPTION OF ACETIC ACID

Assoc. Prof. Štrkalj A. PhD.¹, Assoc. Prof. Glavaš Z. PhD.¹, Prof. Hršak D. PhD.¹
Faculty of Metallurgy – Sisak, University of Zagreb, Croatia¹

strkalj@simet.hr

Abstract: Possibility of using waste mold sand for removal of acetic acid from the aqueous solution was studied in this article. Green sand can be used several times in mold making. When the properties of green sand are not suitable for further use, it becomes waste. Waste mold sand was used in this article as an adsorbent for the removal of acetic acid from the aqueous solution. During the adsorption process, the influence of the amount of the adsorbent and contact time adsorbent/adsorbate (waste mold sand/acetic acid) on the capacity of the adsorption process was monitored. Amount of waste mold sand was varied from 25 to 125 g. Contact times were as follows: 15, 30 and 60 minutes. The obtained results indicate that the adsorption of acetic acid on the waste mold sand occurred at all used combinations of these parameters. However, for all used contact times, the greatest adsorption capacity is achieved when the ratio of waste mold sand/acetic acid was 25 g/100 mL. For all the used amount of adsorbent, the highest adsorption capacity, i.e. dynamic equilibrium was achieved very quickly, after 15 minutes. The obtained results are in accordance with the chemical composition of the waste mold sand.

Keywords: WASTE MOLD SAND, ADSORPTION, ACETIC ACID, EFFICIENCY OF ADSORPTION

1. Introduction

Today, there are various methods for the production of castings, such as sand casting, die-casting, centrifugal casting, shell casting, etc. Sand casting is used for production of around 80 % of castings. This process is suitable for ferrous and non-ferrous castings.

Between the sand casting processes, green sand is the most widely used [1 – 3]. This is actually a mixture which consists of silica sand

(> 90 %), a binder (bentonite clay) and various additives which improve the properties of the mixture.

Green sand can be several times used for mold making. The properties of the green sand deteriorate with the increase in the number of cycles of use. It becomes waste when its properties are not suitable for further use.

Figure 1 schematically shows the status of the green sand (waste/non-waste).

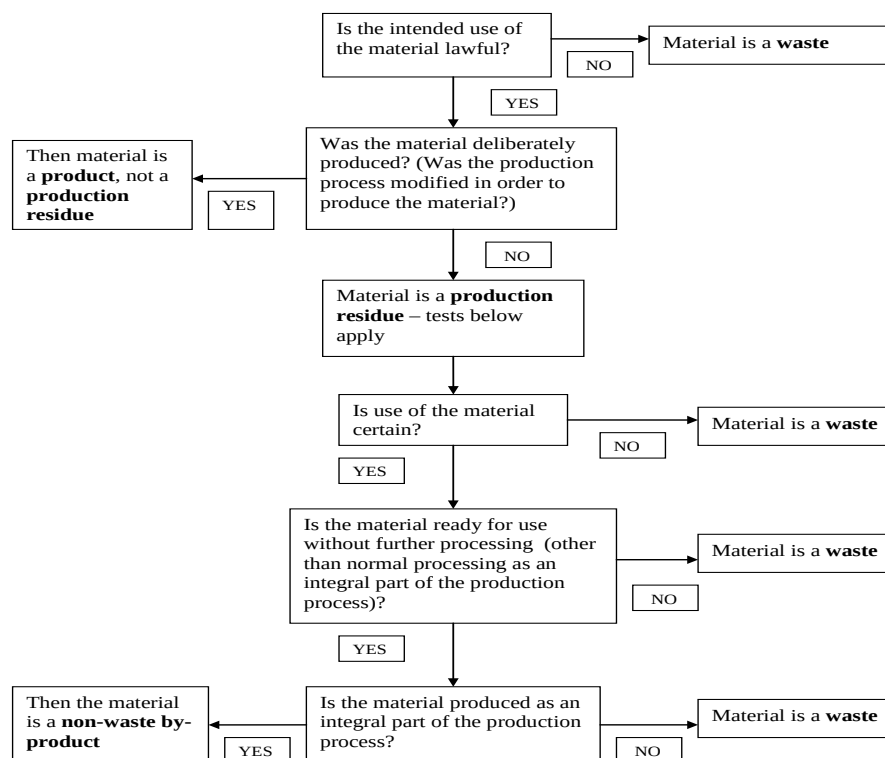


Fig. 1 Schematic diagram of determination of the status of the green sand (waste/non-waste) [4]

Foundry sand which is not suitable for further use in the production process of casting is recycled or disposed at an

appropriate landfill. [5]. The annual amount of spent sand that was created in foundries ranges from 6 to 10 million tons [5, 6].

Of this amount, only less than 15% can be recycled in a cost-effective and safe manner [5, 6].

Recent research has focused on the possibility of using green sand as a potential agent for the removal of heavy metals and organic pollutants from wastewater [7]. Both types of pollutants do not negatively affect the growth and reproduction of living beings. However, increased concentrations can be very harmful, carcinogenic and even deadly. For this reason, they should be removed from wastewater. Adsorption is the most economical method for their removal. Influence of the amount of the adsorbent and contact time adsorbent/adsorbate (waste mold sand/acetic acid) on the capacity of the adsorption process was monitored in this article.

2. Materials and Methods

Waste mold sand that was used in this study originates from one cast iron foundry in Croatia. Standard elemental analysis was used to determine the chemical composition of the waste mold sand. The obtained results are shown in Table 1.

Table 1: Chemical composition of waste mold sand

Composition	w, %
SiO ₂	90,0
Al ₂ O ₃	1,6
Fe	6,8
Ca	0,55
Mg	0,08
Mn	0,04
Ni	0,004

Mineralogical composition of waste mold sand is shown in Figure 2.

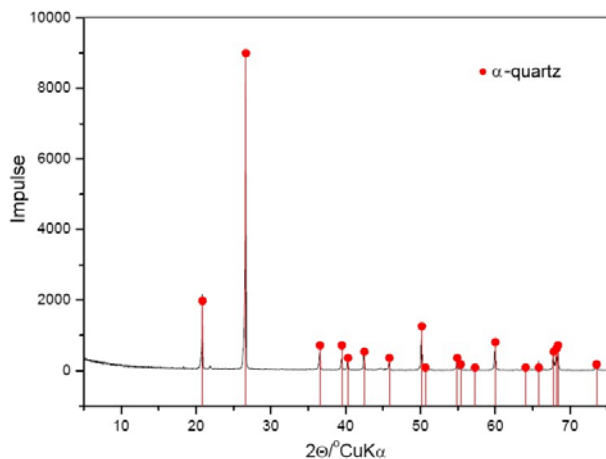


Fig. 2 XRD analysis of waste mold sand

The adsorption experiment was monitored a batch method. In plastic vessels was placed 25, 50, 75 and 125 g of waste mold sand. After that, the waste sand was placed in contact with 100 mL of acetic acid solution whose concentration was 0.1145 mol/L. Thus prepared adsorption systems were in contact 15, 30 and 60 minutes. Filtration was carried out after the expiration of the aforementioned contact time. The concentration of acetic acid was determined by titration with 0.1 mol/L NaOH. Adsorption capacity was calculated from the obtained data (equation 1):

$$q_t = \frac{c_0 - c_t}{m} \cdot V \quad (1)$$

where V is volume of acetic acid (L), m is mass of waste mold sand (g), c_i and c_e are the initial and final concentration of acetic acid (mol/L).

3. Results and Discussion

Influence of the contact time and amount of the adsorbent on the adsorption capacity is shown in Figure 3.

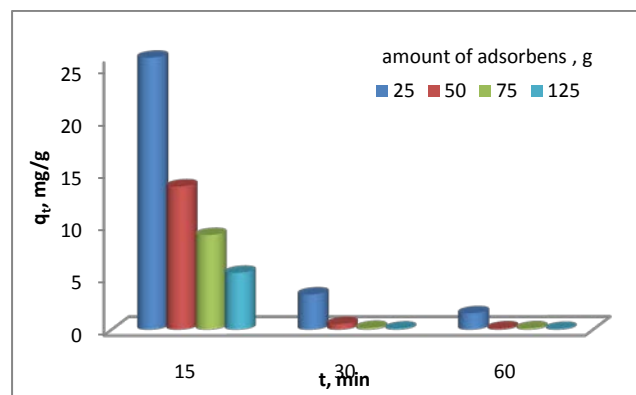


Fig. 3 Influence of the contact time (t) and amount of the adsorbent on the adsorption capacity (q_t)

Figure 3 shows that the best adsorption capacity was achieved when the ratio of adsorbent/adsorbate was 25 g/100 mL. Increasing the amount of adsorbent resulted in a decrease the adsorption capacity for all three of contact time. The initial concentration of acetic acid that was used in this study was relatively low (0.1145 mol/L), and it is possible that it is not sufficient for the binding to the larger quantity of adsorbent.

Comparison of the adsorption capacities and the contact time adsorbent/adsorbate shows that the maximum adsorption capacity is achieved within 15 minutes for all tested amounts of adsorbent. Since the adsorption capacity decreases after 15 minutes, it can be concluded that the dynamic equilibrium was achieved relatively quickly, within 15 minutes. Adsorption capacity decreases after 15 minutes, which may indicate the occurrence of desorption. Desorption occurs when the adsorbate by means of physical forces binds to the adsorbent. Physical forces are not strong and allow release of adsorbate from the surface of the adsorbent, which is manifested as a decrease in adsorption capacity [8].

Regardless of the possibility of desorption, waste mold sand can be used for the removal of acetic acid at all the studied parameters. This is supported by the facts related to the chemical and mineralogical composition. The mold mixture consists of 90% SiO₂ (Table 1, Figure 2), a binder (bentonite clay) and various additives. Each of these components is a good adsorbent. Addition to the mentioned components, waste mold sand contains a certain amount of scale which also enhances its capability of adsorption [9].

3. Conclusion

The adsorption of acetic acid from the aqueous solution on waste mold sand can take place in the tested conditions.

The largest adsorption capacity was achieved when the ratio of adsorbent/adsorbate was 25 g/100 mL for all three contact times.

The increase in contact time adsorbent/adsorbate resulted in a decrease of adsorption capacity. Dynamic equilibrium was achieved within 15 minutes at all amounts of the adsorbent.

LITERATURE

- [1] Jorstad J., Krusiak M. B., Serra J. O., Fay V. L., Aggregates and Binders for Expendable Molds, chapter in ASM Handbook, Volume 15, Casting, Ohio, ASM International, Materials Park, 2008., 528 - 548.
- [2] Green Sand Molding, chapter in ASM Handbook, Volume 15, Casting, Ohio, ASM International, Materials Park, 2008., 549 - 566.
- [3] Brown, R., Foseco Ferrous Foundryman's Handbook, England, Butterworth-Heinemann, 2001.
- [4] <http://eurlex.europa.eu/legalcontent/EN/TXT/?uri=celex%3A52007DC0059>
- [5] Back, E., Klussman, H.G., Walter, N., New development of furan cold resins, Giesserei, 86(4), 1999, 107-108.
- [6] Lindsay, B. J., Logan, T.J., Agricultural Reuse of Foundry Sand, Journal of Residuals Science & Technology, 2(1), 2005, 3-10.
- [7] Štrkalj, A., Glavaš, Z., Brnardić, I., Application of Foundry Waste for Adsorption of Hexavalent Chromium, Chemical and biochemical engineering quarterly, 27 (1), 2013, 15—19.
- [8] Aarden, F. B., Adsorption onto heterogeneous porous materials: equilibria and kinetics, Technische Universiteit Eindhoven, Eindhoven, Netherlands, 2001.
- [9] Glavaš, Z., Štrkalj, A., Određivanje efikasnosti adsorpcije pojedinih komponenti kalupne mješavine, *Proceedings book of International Conference MATRIB 2015*, 25-27.06.2015., Zagreb, Hrvatsko društvo za materijale i tribologiju, 146-150.

CALCULATION ALGORITHM FOR CYCLE LENGTH OF SIGNALIZED INTERSECTION

Assist. Prof. PhD Saliev D.

Technical University of Sofia, Faculty of transport, Department of Combustion Engines, Automobile Engineering and Transport, Bulgaria
durhan_saliev@tu-sofia.bg

Abstract: Traffic lights regulation reduces conflict points in intersection of traffic flows trajectory and provides their safety crossing. The main in installation of traffic lights is determination of a cycle length which guarantee minimum waiting time of traffic flows at the junction. The paper presents a calculation algorithm for the cycle length of a traffic light junction according to traffic flows intensity, saturation flows and day periods which are have deferent intensity.

Keywords: TRAFFIC FLOWS, CYCLE OF TRAFFIC LIGHT, TRAFFIC LIGHT JUNCTION

1. Introduction

Traffic lights regulate road traffic across junctions where the conflict zones between traffic flows are not separated from one another. They are applied in order to increase safety and traffic capacity. The major drawback of regulation with traffic lights there is a waiting time of all flows crossing intersection [2]. Traffic light regulation calls for the implementation of certain conditions. The most influential factor when deciding whether or not to use a traffic light at a given junction is the intensity of the traffic flows passing through this junction.

2. Prerequisites and means for solving the problem

The main issue when regulating junctions by traffic lights is how to determine the optimal cycle length for the existing road and traffic conditions. For achieving minimum waiting times, it is necessary to first determine the periods of the day when it is possible to use different cycle lengths to regulate the traffic at a given junction, thus differentiating rush hours from the other periods of the day.

The length of the traffic light cycle is to a large extent affected by the number and type of phases for allowing traffic to pass through a given junction. They are determined according to the specific traffic and road conditions for a given junction as follows:

- Intensity of traffic flows by direction, which largely affects the decision which traffic flow to cross the junction in each of the phases;
- Type of intersection – three-way intersection, four-way intersection, etc.;
- Junction configuration – the width and number of entry and exit lanes are decisive;
- Complexity of the junction – it depends on the number and type of conflict points between traffic flows;
- Others – coordination with other traffic lights, pedestrian crossings, left-turn prohibition and other considerations related to traffic organization in the junction area.

The safe passage of traffic flows between the different phases is ensured by the change intervals, which guarantee that the last car of the exiting traffic flow will have exited the conflict zone by the time the first car of the entering traffic flow reaches it. The change intervals depend on the configuration and geometric dimensions of the junction. From the point of view of crossing the junction safely, their duration is the part of the traffic light cycle which cannot be changed.

3. Results and discussion

The requirement for optimal cycle length was achieved by developing a cycle length calculation algorithm.

The basic input data for the algorithm are:

- Intensity of traffic flows crossing the junction (I_a), veh/s;
- Length of the period of the day whereof the calculations are

made (t_{pd}), s;

- Minimum green time for each phase ($t_{g\min}$), s.

The number and type of phases for allowing traffic flows to pass through the junction are determined successively. If traffic lights are available, they may not be changed.

The change periods are determined according to the established conflict zones during changes of phases. One of the methods used for this purpose is described by Moore [3].

The saturation flow is determined based on the calculated change period.

It is assumed that the change period for a given phase (t_{ti}) is equal to the transition time of a vehicle through the intersection (t_{pc}). It is determined with the help of a study which includes measurements of the time that the vehicles in the queue need to set off when the traffic light changes to green. The transition time of each car in the queue and the time between them are both measured. The results show that the headway between vehicles (Δt_{bc}) passing through the signalized intersection is one second.

According to the transition time of a car and the headway, the following values are determined:

$$A_e = \frac{t_{pc}}{\Delta t_{bc}}, \text{ veh} \quad (1)$$

$$t_p = 2t_{pc}, \text{ s} \quad (2)$$

Where:

A_e - Number of vehicles entering the intersection during the transition time of a vehicle, veh;

t_p - Transition time of A_e , s.

The saturation flow of a single lane of the roadway is determined:

$$I_{pl}^f = \frac{A_e}{t_p}, \text{ veh/s} \quad (3)$$

The saturation flow is determined by using (4).

$$I_p^f = I_{pl}^f * l_t, \text{ veh/s} \quad (4)$$

Where:

l_t - Number of lanes for the respective flow.

Each flow of the given phases requires enough green time (t_{ng}^f) to guarantee its smooth passing during the period of the day for which the calculations are made. The required green light time is calculated as follows:

$$t_{ng}^f = \frac{t_{pd} * I_a^f}{I_p^f}, s \quad (5)$$

After calculations for each flow are made, the sum of the green times required for each phase $\sum_{i=1}^n t_{ng}^{f_i}$ is calculated as well, where “i” is the number of phases.

We calculate the sum of all change periods for the whole period of the day for which the cycle length is calculated by using the following equation:

$$\sum_{i=1}^n t_{ti} = t_{pd} - \sum_{i=1}^n t_{ng}^{f_i}, s \quad (6)$$

We determine the number of cycles for the period of the day whereof the calculations are made (N_{cp}):

$$N_{cp} = \frac{\sum_{i=1}^n t_{ti}}{\sum_{i=1}^n t_{ng}^{f_i}} \quad (7)$$

The cycle length is calculated as follows:

$$t_c = \frac{t_{pd}}{N_{cp}}, s \quad (8)$$

After calculating the cycle length, we calculate the green time for each phase of the cycle. For this purpose, the following ratio is used:

$$\gamma_i = \frac{I_p^{f_i}}{I_a^{f_i}} \quad (9)$$

The green time for each phase is calculated according to (9).

$$t_g^f = \frac{t_c}{\gamma_i}, s \quad (10)$$

One constraint of the algorithm is the provision of minimum green time for each phase.

A generalized block diagram of the calculation algorithm for cycle length for signalized intersection is shown in fig. 1.

The determined cycle length is optimal for the intersection in the existing traffic conditions. The lengths of the phases can be further optimized by following the algorithm described in detail in [1].

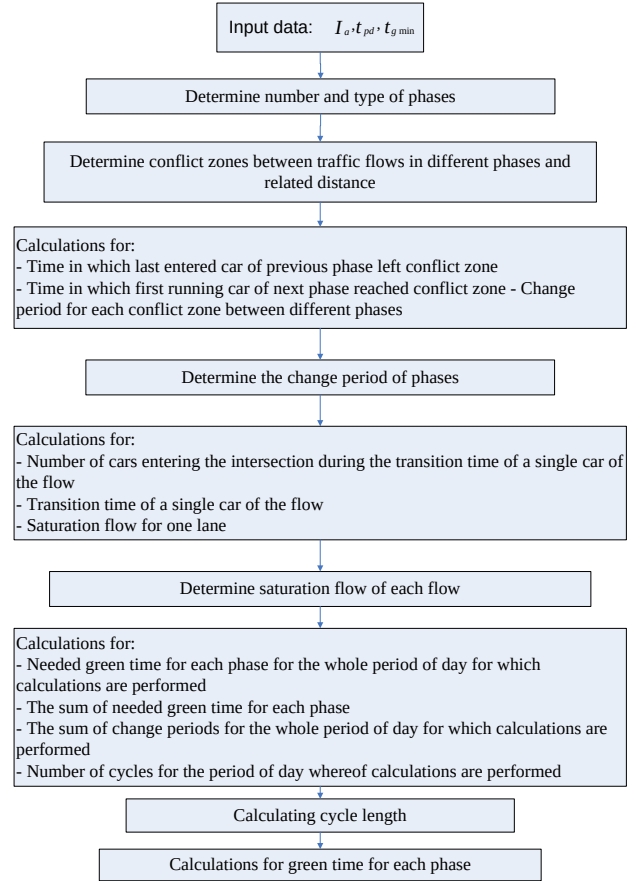


Fig. 1 Generalized block diagram of the calculation algorithm for cycle length for signalized intersection

4. Conclusions

The presented calculation algorithm for cycle length of signalized intersection has the following major advantages:

1. Allows calculation of the cycle length for each period of the day regardless of its duration.
2. The input data are determined by a single analysis of the intensity of traffic flows.
3. Little input information is required for the determination of change periods.
4. A value of the cycle length, which is optimal in the existing traffic conditions, is determined.
5. The determined green times guarantee the smooth passing of cars during the given period of the day.

References

- [1] Салиев, Д. (2013). Моделиране на пътнотранспортното движение при на стъпване на аварийни ситуации. Докторска дисертация, ТУ – София, София, България.
- [2] Сотиров, Д., 1983. Проектиране на пътища. София, Техника.
- [3] Moore, P., 2011. Streamlining phase intergreen measurement for traffic signal junction. Traffic Engineering and Control, July, pp.283-285.

ALUMINUM NANOSTRUCTURED COATINGS AS ALIGNMENT LAYERS FOR LIQUID CRYSTAL MIXTURES

Prof. Dr. Alexander G. SMIRNOV¹, Dr. Andrey A. STSIAPANAU¹, Prof. Dr. Victor V. Belyaev², Dr. Denis N. Chausov²
 Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus¹
 Moscow Region State University, Moscow, Russia²

smirnov@bsuir.by

Abstract: Aluminum nanostructured coatings are the promising alternatives to transparent semiconductors or metals. In this paper we describe the fabrication of these coatings by electrochemical anodization of aluminum deposited by magnetron sputtering on a glass substrate. The process of anodization is strictly controlled by process parameters followed by selective chemical etching of aluminum oxide. Optical transmittance and surface resistance depend on the mesh dimensions of Al nanostructured coatings and have been investigated theoretically and experimentally.

Keywords: INDUSTRY 4.0, NANOSTRUCTURED COATINGS, ALIGNMENT, LIQUID CRYSTALS

1. Introduction

Main requirements for transparent conductive electrodes (TCEs) are good transparency in a limited and well-defined range as well as suitable conductivity. E.g., the wavelength interval constitutes 300nm-2500 nm for photovoltaic and 400-700 nm for displays. Nowadays the best material to reach this goal is indium tin oxide (ITO). It is commonly used in many kinds of displays, light-emission diodes, solar cells and other devices. The average transmission for ITO is approximately 80-90% depending on thickness variation. For smaller thickness, ITO has better transmission and resistance and vice versa. The range of ITO sheet resistance is 10-100 $\Omega/\square$ [1]. Assuming ITO is “ideal”, novel TCEs should have the same properties or even better.

The metal-based thin transparent films are attractive due to their plasmonic properties and better flexibility. Planar metal films have poor optical performances, however a special nanostructuring can increase the transmission. The cross-linked Cu layer with average 61 and 75% transmittance and sheet resistance 10 and 15 $\Omega/\square$ for 120 and 200 nm grating line width were demonstrated correspondently [2]. Another nanostructuring shape is a nanoholey structure. The main feature of these structures is the independence on the light polarization at defined holes arrangement. In [3–5] data on transmission, reflection and absorption vs different hole size, inter hole distance and thickness are shown. Besides, development of other types of conductive films on the base of organic materials is an important task for flexible displays. In this paper, two simple methods of transparent conductive metal electrodes fabrication were proposed and realized. There optimal optical and electrical parameters were found and systematized. In addition, some organosilicon materials have been studied from the point of view of their application as transparent electrodes.

2. Experimental results

Anodized aluminum transparent conductive films: A glass substrate with 200 nm aluminum (Al) is used for the first method of the TCEs fabrication [6]. The full process is illustrated on Fig. 1, where, for simplicity, the holey alumina (Al_2O_3) is not included. When the electrochemical anodization of Al starts the holes grow with sphere shape. At time t_0 (step **a**) the holes (sphere) contact with the substrate and an aluminum electrode is forming. At this position the transparency is small and a further anodization is required (step **b**). At time $t_1 > t_0$ the transmission increases and at time $t_2 > t_1$ has the biggest values. The conductance has opposite behaviour and has the smallest value at time t_2 . Thus trade-off between transparency and conductivity is necessary.

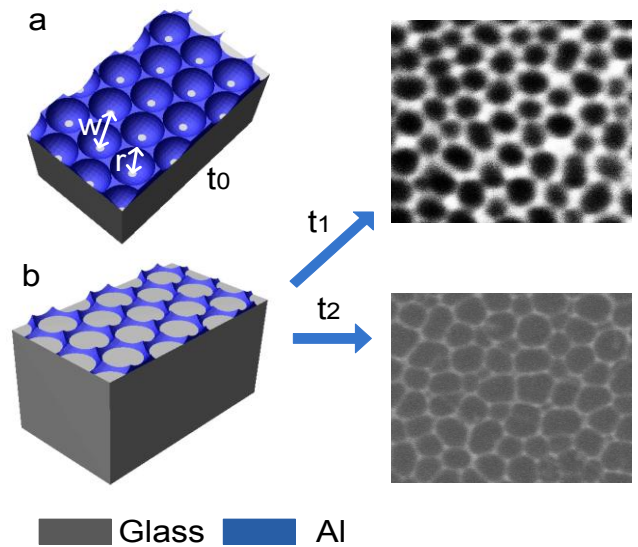


Fig.1. First method of TCEs fabrication
 a) The beginning of Al TCE formation (time t_0); b) The end of Al TCE formation (time t_1 or t_2);

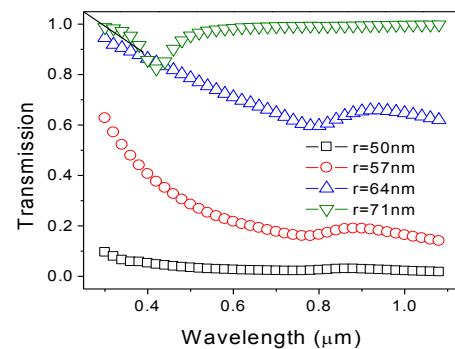


Fig.2. Simulated optical properties for Al TCE with $r=50, 57, 64, 71$ nm and $w=100$ nm.

In order to find the optimal parameters the FDTD Lumerical [7] and COMSOL Multiphysics [8] packages are used for optical and electrical properties simulation accordingly. The 10-20 $\Omega/\square$ sheet resistance for hole (sphere) radius $r=60-70$ nm and inter hole distance $w=100$ nm was obtained.

The simulated optical properties for hole (sphere) radii with $r=50, 57, 64, 71$ nm and inter hole distance $w=100$ nm is shown in Fig. 2. The $r=50$ nm and $r=57$ nm correspond to time t_0 and t_1 accordingly. The $r=57$ nm is an intermediate time value and $r=71$ nm ($\approx 0 \cdot \sqrt{2}$) is value when conductance equals $0 \Omega/\square$. In this case the trade-off between transparency and conductivity must satisfy condition 1.2-1.4 r to obtain the average transmission 70-80% for range 300-1000 nm and 10-20 $\Omega/\square$ sheet resistance.

The second proposed TCE formation method includes three steps as illustrated on Fig. 3. The step **a** is aluminum deposition followed by anodization and holes widening in the solution containing phosphoric acid. Then the metal (gold Au in our case) is deposited by e-beam evaporation (step **b**). The final step **c** is the transfer of obtained TCE to adhesive substrate.

Optical properties for Au TCE at different hole size $r=100, 150, 200$ nm, inter hole distances $w=2r+25, 50, 75$ nm and thickness $d=25, 50$ nm are simulated using commercial software FDTD Lumerical [7]. The larger holes size provides better average transmission, when larger inter hole distance and thickness have opposite dependence. The Au electrode only absorbs a part of light for the range of 300-600 nm due to localized plasmonic resonance. At $\lambda > 700$ nm the reflection increases.

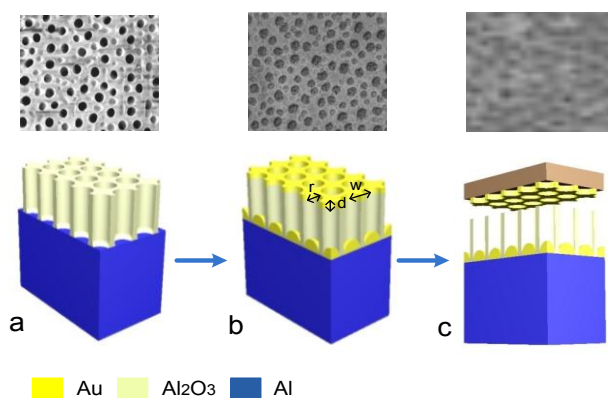


Fig.3. Second method of TCEs fabrication
a) aluminum deposition, anodizing and holes widening;
b) metal deposition;
c) metal TCE transferring.

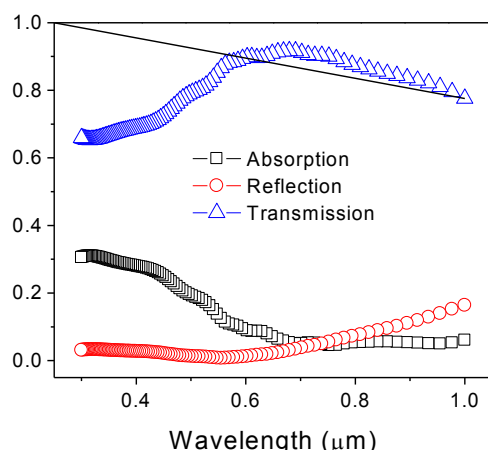


Fig.4. Simulated optical properties for Au TCE with $r=100$, $w=25$ and $d=25$ nm.

The structure with $r=100$ nm, $w=25$ nm and $d=25$ nm has better average transmission for the range 300-1000 nm (Fig. 4) and equals to 82.5%. The 10-20 $\Omega/\square$ values were obtained for 25-50 nm TCEs thickness by four probe method.

Organosilicon transparent conductive films: Methods of synthesis of organosilicon substances (OS) and formation of dielectric films for liquid crystal alignment are described in [9,10].

Organosilicon substances with polar groups at the silicon atom have been synthesized to make transparent films with increased electroconductivity. There the OS comprising cyanoethyl and phenyl (2-hexoxy) substituents at the Si atom as well as functional ethoxy groups that interact with active substrate's centers and form a chemically bonded film.

To increase the film conductivity a toluene OS solution was mixed with a micellar solution of silver nanoparticles (produced by Nanomet Co., Moscow, Russia [11]). The solution is a triple system of reverse micelles: water solution of an Ag salt/a surface active substance/nonpolar solvent. The nanoparticle formation takes place in the water nucleus of the micelle formed by molecules of an anionic surface active substance (acid). The silver nanoparticles are as big as 5-20 nm.

The transparent film thickness is 100-150 nm. The films formed from the OS toluene solution are transparent and colorless. The films formed from the OS and Silvernano-1 solution have ~20% lower transparency, they are yellowish. Round nuclei are to watch in a microscope photo (Fig.5). However in this experiment the film resistance was too big for practical application in displays. Improvement of the film structure is in progress.



Fig.5. A microphotograph of a transparent conductive film formed from the OS and Silvernano-1 solution.

4. Conclusion

Two methods of transparent conductive metal electrodes fabrication by electrochemical anodization technology are presented. The obtained transmission in the range of 300-1000 nm and its sheet resistance are the same as at ITO reference electrodes. These electrodes can be applied in the various optoelectronic devices. The coatings made of organosilicon materials and silver nanoparticle solution should be improved for their application as transparent electrodes.

Acknowledgements

The work is partly supported by Belarusian Republican Foundation for Basic Researches (grant No T16P-200) and by Russian Foundation for Basic Researches, grant No 12-07-90006_Bel_a, 14-07-00574_a.

References

- [1] A.L. Dawar and J.C. Joshi, J. Mater. Sci. Lett. **19**, 1-23 (1984)
- [2] M.G. Kang and L.J. Guo, J. Vac. Sci. Technol. B, **25**, 2637-2641 (2007).
- [3] W.A. Murray and W.L. Barnes, Adv. Mater., **19**, 3771-3782 (2007).
- [4] X. Shou, A. Agrawal and A. Nahata, Opt. Express, **13**, 9834-9840 (2005).
- [5] Q. Wang, J. Li, C. Huang, C. Zhang and Y. Zhu. Appl. Phys. Lett., **87**, 091105-091107 (2005).
- [6] A. Smirnov, A. Stsiapanau, A. Mohammed, E. Mukha, H.S. Kwok, A. Murauski, Proc. SID Symposium "Display Week-2011", Los-Angeles, 1385-1387 (2011).
- [7] Trial Versions of FDTD Solutions <http://www.lumerical.com>
- [8] COMSOL Multiphysics <http://www.comsol.com>
- [9] V.V. Belyaev, and V.G. Mazaeva, SID '11 Digest, pp.1412-1415 (2011).
- [10] M.V. Sobolevsky, et al., Mol. Cryst. Liq. Cryst., **329**, 293-304 (1999).
- [11] <http://www.nanomet.ru/chemical-elements/silver-nanoparticles/>